Information to Support the Human Performance Modeling of a B757 Flight Crew during Approach and Landing

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1 Introduction

The NASA Aviation System Program (AvSP) was created to perform research and develop technology to reduce the rate of fatal aircraft accidents in the US. Under AvSP, the System-Wide Accident Prevention project uses current knowledge about human cognition to develop mitigation strategies to address current trends in aviation accident and incident profiles. System-Wide Accident Prevention is comprised of four elements, one being Human Performance Modeling (HPM). The objective of the HPM element is to develop predictive capabilities to identify likely performance improvements and/or error vulnerabilities in human/system operation. For FY02, this element is investigating the application of HPM to predict the human performance of flight crews utilizing the Synthetic Vision System (SVS) in the cockpit. SVS depicts a clear, 3-dimensional, out-the-cockpit view of terrain, obstacles, runways, etc. to the pilot, regardless of the actual visibility or weather conditions. The SVS display is situated in the cockpit next to the primary flight display.

The first step in the FY02 SVS modeling effort is to create a baseline human performance model of the flight crew *without* SVS. In other words, the baseline model represents today's flight deck equipment and operations. NASA decided that the flight deck for this HPM effort would be the Boeing 757. This decision was driven by the fact that SVS flight tests using a NASA-owned B757 have been conducted. The data collected from the flight tests may be used for comparison with the HPM predictions. The NASA HPM element directed the FY02 effort to focus on the approach and landing phases of flight. Indeed, improved pilot situational awareness of terrain and obstacles during approach and landing is expected to be one of the biggest benefits of SVS.

To get the FY02 effort underway, NASA requested that Micro Analysis and Design provide *baseline* (i.e., no SVS) B757 approach/landing task information to the modeling teams. This process provides relevant information to the teams for building models without requiring those teams to expend their time and resources collecting the information. The baseline information provided by this report will be followed by SVS-task related information. The SVS-task related information will be delivered separately a few weeks from now.

2 Objective

The objective of this research was to provide the FY02 HPM teams with the necessary information to model the flight crew of a B757 during the approach and landing phases of flight. For this round of research, NASA has directed us to evaluate instrument landing system (ILS) approaches in Category I conditions and ILS approaches in visual meteorological conditions (VMC) conditions. We made the assumption that our audience, the modelers, are familiar with aviation terms in general, but have little idea how to fly a plane, much less a B757. Hence, one goal that we strived to meet was to provide enough background information about the B757 and approach/landing phases of flight that the modeler would understand not only what a pilot does, but why he does it. In particular, when considering cognitive decision points, it is important that the modeler understand why a pilot makes the decisions that he/she does. To know this requires a fair amount of aviation domain knowledge. It is our hope that this domain knowledge is accurately and clearly presented. Also, to provide further assistance to the modelers and to limit us from reinventing the wheel, we have included an FAA pilot/controller glossary in Adobe Acrobat format in a separate attachment. Furthermore, as we the authors are also modelers, we wrote this paper with the perspective of what we would need to know to build a B757 approach/landing model. Thus, if something is absent from this effort, it was omitted because we were unable to collect it with the resources and time available. We sincerely hope the individual modelers contact us if anything appears missing, unclear, inconsistent, or just plain wrong.

3 Technical Approach

The first step in this research was to conduct a literature search to find pertinent documentation on the B757 and on the pilot tasks for air transport carriers. Fortunately, the literature search proved fruitful so the next step was to digest the information that had been collected. A functional analysis of the commercial flight domain by Douglas Aircraft provided a detailed sequence of events, functions, and tasks on a representative flight from Los Angeles to New York. The section of this document concerning the functional analysis during approach and landing was particularly useful for preparing for interviews with four subject matter experts (SME).

At around the same time as the interviews were being coordinated, the NASA HPM manager offered to arrange for us an opportunity to spend a morning with pilots in the NASA Ames B747-400 full motion simulator (FAA level 4-certified, the highest sim rating available) as they performed approaches and landings. Although a B747-400 and B757 handle quite differently, particularly during landing, the tasks and primary instrument display are very similar. In addition, we anticipated that the sim ride would be very useful for setting the stage to discuss cognitive decision points.

The timing of the SME interviews forced the team to split. John Keller went down to Orlando to interview two pilots while Ken Leiden headed to Ames Research Center for the sim ride and interviews that followed. We call it a sim ride rather than a sim experiment because no formal data was collected other than a frame-synchronized, 4-quadrant video tape. The tape of the four quadrants shows the primary flight display, navigation display, the view out the cockpit, and the flight crew.

The pilots that participated in the interviews had the following flight credentials.

1. Retired United Airlines captain with 25,360 hours, including 4,000 hours in a B747, 3,000 of which are from the 747-400 series.
2. Current Delta Airlines captain with over 18,000 hours, including over 8,000 hours in a B757/767 (note that these two aircraft share a common pilot type rating).
3. Current American Airlines type rated first officer with 6,000 hours, including over 2,000 hours in a B757/767.
4. Retired line check airman and Associate Professor at Embry-Riddle Aeronautical University with over 21,500 hours, including 9,000 hrs in a MD-80.

The information collected from both the literature review and the SMEs was integrated and then decomposed into five topics:

- Background information about the aviation domain, with an emphasis on approach/landing and the B757 flight deck (Section 4)
- Behavioral task analysis of the approach and landing (Section 5.1-5.3)
- Situation awareness information requirements (Section 5.4)
- Discussion of B747-400 simulator runs (Section 5.5)
- Cognitive decision points during approach and landing (Section 5.6)

Appendix A has a detailed post-accident analyses of four international accidents during the approach/landing phase of flight. These reports are included because of the perspective and insight that can provide to the modelers.

4 Background Information

Although this research is focused on the B757, the information presented here and in section 4.1 applies to all air transport carriers. Air transport carriers (e.g., airlines and cargo carriers) are required to file instrument flight rules (IFR) flight plans. Aircraft on IFR flight plans are required to follow air traffic control (ATC) directives. In return, ATC keeps aircraft safely separated, both in the air and on the ground.

This research focuses on the approach and landing phases of flight. Figure 1 shows the relationship of these phases to the other phases of *normal* flight (adapted from Alter & Regal, 1992).

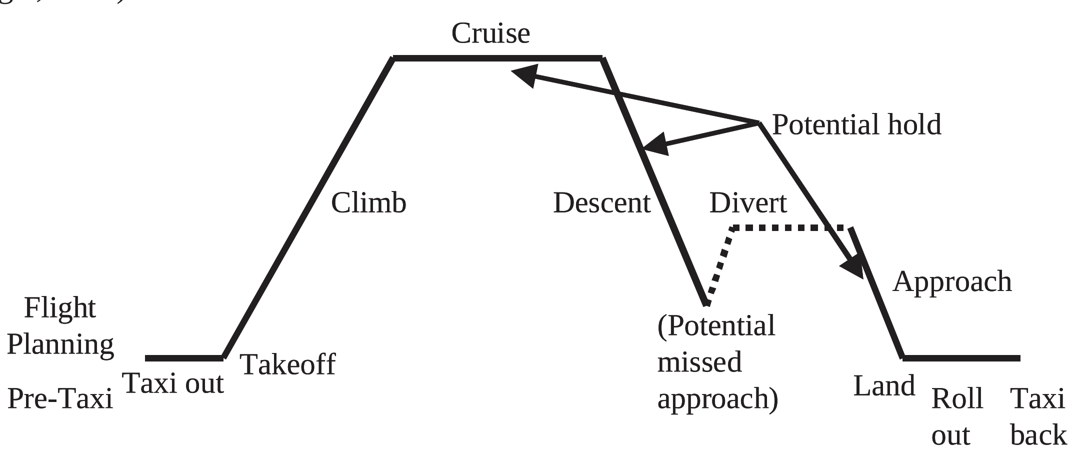

Figure 1. Normal phases of flight

Although the missed approach and subsequent divert phases of flight are shown in Figure 1, the occurrence is rare amongst professional pilots. Two of the SMEs estimated the occurrence of missed approaches to be about one missed approach per year per pilot or, based on 20 landings per month per pilot, 1 missed approach per 240 landings. Similarly, the hold phase of flight, which can be requested by air traffic control during the cruise, descent, or approach phases of flight, has become less common in recent years due to a more strategic methodology for spacing and sequencing arriving aircraft. That said, missed approaches and holds are still considered phases of normal flight. This is in contrast to emergency situations, which are abnormal and outside the scope of this research.

4.1 Approach Phase of Flight

The approach phase begins at the bottom of descent and ends just prior to the flare in the landing phase. During the approach phase, pilots of air transport carriers must follow instrument approach procedures regardless of visibility. Instrument approach procedures have been meticulously designed to transition aircraft safely from the en route airway structure to the arrival airport by specifying the heading and minimum altitude allowed to avoid both terrain and nearby air traffic patterns. This is typically done in three segments. Since the segment description depends on the type of approach, the segments will be described in more detail in Section 4.1.2.

Instrument approaches are classified into two types – nonprecision and precision. The difference is determined by the type of navigation aids available at the airport as well as the corresponding instrumentation available on the flight deck. The B757 is equipped with a full range of instrumentation to support virtually all types of nonprecision and precision approaches. A nonprecision approach provides only lateral guidance to the pilot whereas a precision approach provides both lateral and vertical guidance. ILS precision approaches for properly equipped runways and flight decks are further delineated into three categories (Category I, II, III) depending on minimum visibility requirements and decision height altitudes. As mentioned earlier, for this round of research, the focus is on ILS approaches in Category I conditions and ILS approaches in VMC conditions.

4.1.1 Instrument Landing System

The instrument landing system consists of three types of transmitters – the localizer, the glide slope, and marker beacons (Nolan, 1994). The **localizer** provides lateral guidance aligned with the runway centerline. The localizer antenna sends a VHF signal that is modulated with a 90 Hz tone and 150 Hz tone corresponding to left and right of centerline, respectively. If the localizer receiver on the flight deck senses that the tones are of equal strength, then the aircraft is aligned with the runway centerline. If the 90 Hz tone dominates, then the aircraft is left of centerline and the aircraft must turn to the right to return to the centerline. Likewise, if the 150 Hz tone dominates, the aircraft is right of centerline. The localizer signal is transmitted at 35 degrees right and left of centerline and is about 7 degrees in height (i.e., starts at level ground and arcs to 7 deg). Between 10 and 25 nm from the antenna, the signal is only certified to be accurate within 10 degrees of right and left of centerline. The signal strength varies greatly between airports. For busy airports like LAX, the signal is strong enough that it can be received 30 miles out whereas at smaller airports the signal may only extend 10 miles.

The **glide slope** provides vertical guidance to direct the aircraft along a glide path (typically 3 degrees) that will intersect with the ground about 1000 ft from the approach end of the runway. The glide slope antenna sends a UHF signal that is modulated with a 90 Hz tone and 150 Hz tone. If the 90 Hz signal dominates, the aircraft is above the glide slope. The aircraft needs to fly lower to pick up the nominal glide slope. Similarly, if the

150 Hz signal dominates, the aircraft is below the glide slope. Although 3 degrees is a typical glide slope, false glide slopes, due to a reflection of the signal off the ground, can occur at around 9 degrees. To avoid tuning into a false glide slope, instrument approach procedures require that aircraft transition to the ILS glide slope intercept at altitude ranges low enough to inhibit false glide slope capture, but high enough to avoid terrain and obstacles. The transmission of the glide slope signal is much narrower than the localizer. The glide slope signal, centered about the 3 degree glide slope, is 3 to 6 degree wide, and roughly 1.4 degrees high.

Marker beacons provide distance measurement relative to the runway. Marker beacons are critical for performing non-precision approaches, but are less important for ILS approaches. For ILS approaches, the marker beacons provide the means to crosscheck the aircraft's glide slope to an actual point in space. The outer marker is typically about 5 miles from the runway threshold. The altitude at which a vertical line from the outer marker intersects the ILS glide slope is referenced on the instrument approach procedures charts (pilots refer to them as approach plates). Thus, if the aircraft is aligned with the ILS glide slope, it should cross the outer marker at the specified approach chart altitude. The beacon receiver onboard the aircraft flashes when the aircraft passes directly over the marker. The middle marker is usually about 3,000 ft from the threshold. If the aircraft is aligned with the glide slope, crossing the middle marker occurs simultaneously with crossing the 200 ft above ground level (AGL) *decision height*. For Category I approaches, the decision to continue with the descent or execute a missed approach is made at or prior to reaching decision height. The decision to execute a missed approach will be discussed in more detail in Section 5.4.

4.1.2 ILS Category I Approach

As mentioned earlier, the approach phase of flight is typically done in three segments. For an ILS approach, these segments can be described as:

Segment	**Begins with:**	**Ends with:**
Initial approach	Transition from Standard Terminal Arrival Route via ATC clearance for altitude, heading, and speed	Localizer intercept
Intermediate approach	Localizer intercept	Final approach fix
Final approach	Final approach fix	Flare prior to landing, or execution of missed approach at or before decision height

The initial approach segment begins when ATC issues a clearance to transition the aircraft from a Standard Terminal Arrival Route (STAR) (or other structured airway route) to the localizer intercept, as depicted in Figure 2. The flight path to the localizer intercept is typically done with a single ATC clearance for altitude, heading, and possibly speed. However, when the controller must slow multiple aircraft for spacing and sequencing, or when the instrument approach procedure requires it, this segment may necessitate multiple clearances (for any combination of altitude, heading, and speed) for each aircraft. In any case, the last of the clearances in this segment will place the aircraft on a heading and altitude to intercept the localizer signal. To simplify the scope of this work, the assumption is made that this segment will involve a single clearance to put the aircraft on an intercept path with the localizer.

It is noteworthy to mention that the approach plates often depict an expected heading for the transition from the STAR to the initial approach. For situations in which spacing and sequencing is not a problem, this heading is typically the heading issued by ATC.

Once the aircraft has intersected the localizer, the intermediate approach segment begins. The aircraft turns to the localizer heading. The aircraft descends and maintains the altitude as specified by the approach plates. This altitude is often referred to as the glide slope intercept altitude (GSIA). However, if ATC directs an altitude that differs from the altitude specified on the approach plate, then the ATC-directed altitude always take priority over the altitude from the approach plate. Indeed, this holds true for all discrepancies between information provided by ATC directives vs. approach plates.

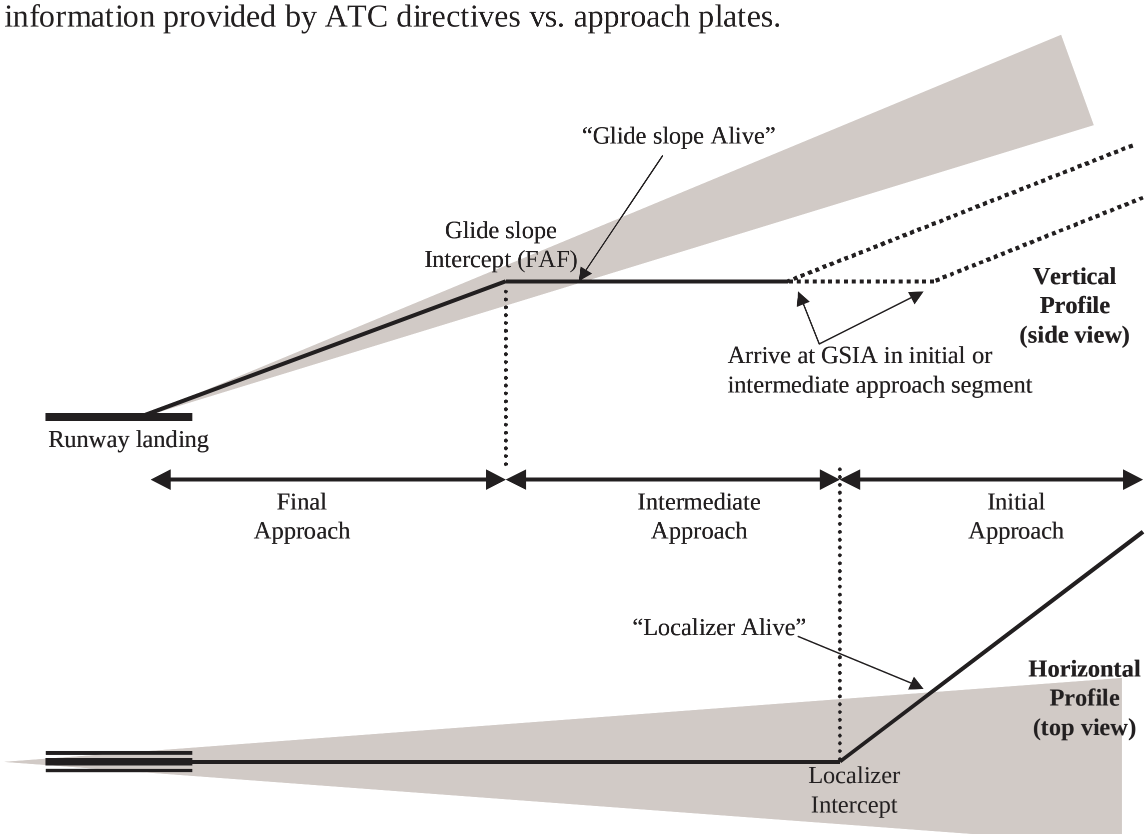

Figure 2. Segments of the ILS approach

It is sometimes necessary to perform a procedure turn during the intermediate approach segment. This situation occurs when the heading of the initial approach segment is nearly opposite the heading for the intermediate approach segment. Comments from the SMEs indicated that the procedure turn is rarely used in US operations. Based on this, the procedure turn was omitted from the scope of this research.

The intermediate approach segment ends and the final approach segment begins when the aircraft crosses the final approach fix. For ILS approaches, the final approach fix (FAF) is defined in one of two ways (FAA Glossary, 2002):

1. For a glide slope intercept altitude identical to that on an approach chart, the FAF is the point that corresponds to the lightning bolt symbol on the approach chart.
2. When ATC directs a higher- or lower-than-published GSIA, it is the resultant actual point of the glide slope intercept.

Thus, for the 2nd case, the FAF is not a fixed point in space, but dependent on the ATC-directed altitude from the intermediate approach segment. The emphasis here is that, despite what is indicated on the approach charts, the final approach begins when the aircraft intersects the glide slope. For example, a lower-than-published altitude will shorten the length of the final approach segment somewhat.

During final approach, the aircraft descends along the ILS glide slope while maintaining alignment with the runway centerline via the localizer. At 200 ft AGL, the pilot must be able to see the runway threshold to proceed with the descent and landing – seeing the approach lights, which extend 2400-3000 ft before the threshold is not sufficient by itself. The reason for this is the visibility may get worse rather than improve, creating a potentially unsafe situation if the aircraft continues to lose altitude. If the pilot cannot see the runway threshold, or for any reason the pilot believes it is unsafe to land, the pilot must execute a missed approach.

4.1.3 Visual approach slope indicator

Most of the lights along the approach path and runway are designed to provide lateral guidance to the pilot. However, the visual approach slope indicator (VASI) system is designed to provide pilots with vertical guidance (i.e., glide slope) information. VASI units project a narrow beam of light (Nolan, 1994) along the glide slope. The light is filtered such that the light above the glide slope is white and the light below is red. The units, either two or three, are spaced about 500 ft apart along the runway. In the case of the two unit VASI system, the pilot is on the glide slope when the closer unit is white and the further unit is red. VASI lights can be seen as far as 20 miles away in VMC. Similar to the ILS, the VASI glide slope is designed to intersect the runway about a 1000 ft from the runway threshold.

4.2 Landing Phase of Flight

Assuming visibility permits the Category I approach to continue, the landing phase of flight goes relatively quickly. After passing through decision height, the pilot is using visual cues to align with the runway centerline. The landing of the aircraft is very much a skill-based task.

4.3 Manual vs. Automated Control

The B757 design allows the pilot to choose the level of automation for guidance and control. In this section, three levels of automation to *control* the aircraft are discussed (guidance is discussed in Section 4.4). The three levels are the flight director, autopilot, and autothrottle:

Flight director

One type of automation is the flight director system. The flight director system does not control the aircraft per se, but rather is a decision aid that provides a visual representation on the primary flight display (PFD) of how the pilot should pitch and/or roll the aircraft to respond to guidance commands. The visual representation is dependent on customer preferences, but is typically in the form of two lines referred to as command bars (discussed in detail in Section 4.4 and depicted in Figure 6). Collectively, the two command bars on the PFD are referred to as the *flight director*. The utility of the flight director can be understood by an example. During an ILS approach, the flight director is positioned and continuously updated on the PFD to effectively guide the aircraft for alignment with the ILS signal. If the pilot can align the attitude of the aircraft with the flight director command bars, then the aircraft will align with the localizer and glide slope.

Analogous to the flight director, but used for engine thrust, the green *cursors* (also called bugs) on the display of the engine indicators depict how the pilot should manipulate the thrust to respond to guidance commands.

Autopilot

The *autopilot* controls pitch and roll by manipulating the aircraft's elevators and ailerons, respectively, in response to guidance commands. (Note that the B757 is yaw stabilized so turning the aircraft requires only a roll angle. Yaw can be controlled by manipulating the rudder via foot pedals, but this is typically only necessary during landing when the aircraft is subject to high crosswinds.)

Autothrottle

The *autothrottle* manipulates the thrust of both engines in response to guidance commands. During approach, pilots typically keep the autothrottle engaged (active) to maintain desired speed until just prior to touchdown.

Based on the SME interviews, the most common way pilots use the flight director, autopilot, and autothrottle during an ILS approach and landing are as follows:

- Full automatic control – flight director **on**, autothrottle **on,** autopilot **on**. Pilots typically use this level of automation through both the initial and intermediate approach segments, ending at either the beginning of final approach (i.e., point of glide slope intercept) or sometimes part of the way down the glide slope depending on VMC or IMC conditions.

- Flight director **on**, autothrottle **on**, autopilot **off –** Pitch and roll is controlled by the pilot's manipulation of the control yoke to follow the flight director command bars on the PFD. Pilots typically use this level of automation during the final approach if the pilot is flying in VMC, but pilot preference really dictates when the transition is made. He/she will crosscheck the flight director with what he/she sees out the window with respect to the runway centerline and VASI lights.

- Flight director **on**, autothrottle **off**, autopilot **off –** Like the previous case, but the pilot must also manipulate the thrust levers to control speed. Pilots typically use this level of automation during the end of the final approach and during landing. Although the flight director is still on, the pilot is often getting cues for lateral and glide slope alignment based on the runway centerline and VASI lights, respectively, rather than the flight director.

4.4 Flight Deck Controls, Instrumentation, and Displays

The B757 flight deck is referred to as a glass cockpit because a computer and CRT display are utilized to represent the traditional instrumentation (e.g., attitude indicator) found in older aircraft. In addition, a glass cockpit allows the functions of several different instruments to be presented on a single display, saving panel space and allowing the pilot to gather the most critical cues for a given task from one display.

The www.meriweather.com website has images of all instruments and displays on the B767 flight deck. Fortunately, Boeing designed the flight decks of the B757 and B767 to be nearly identical. The shared flight deck design feature has many advantages, one being it enables pilots to earn a common pilot type rating for both aircraft. In addition, it means the B767 information on the meriweather website is directly applicable to goals of this B757 research. The meriweather website features a Javascript capability that allows the user to "mouse over" a feature on the instrument display to learn more about it. Because of this capability and the desire to not reinvent the wheel, only a brief overview of the flight deck is presented in this document with an emphasis on depicting the primary controls, instrumentation, and displays needed during the approach and landing phases of flight. An assumption is made that if modelers have a need for more information about the flight deck, they will use the website capability to familiarize themselves as needed.

Figure 3 and Figure 4 depict an overview of the B757/767 flight deck and center instrument panel, respectively. The primary flight deck equipment that will be discussed in this section include the following:

- Flight management system
- Mode Control Panel
    - Guidance Functions
- Primary Flight Display
- Navigation Display

4.4.1 Flight Management System

The function of the flight management computer (FMC) is to assist the pilot with the planning and execution of the flight route. During the flight planning phase of flight (see

Figure 1), the pilot enters flight route, aircraft, and expected conditions information into the FMC via the control display unit (CDU) interface (Casner, 2001). Collectively, the FMC and CDU are referred to as the **flight management system** (FMS). Information about the flight route includes *expected* departure runway and departure procedure, cruise altitude, arrival and approach procedures, and runway assignment. That said, the actual flight route can always differ depending on weather and ATC requirements, often requiring the pilot to reprogram the FMC in flight. The FMC is capable of calculating the optimal flight path and economical speeds during the climb, cruise, and descent phases of flight. When an aircraft is following the flight route in the FMC, it is often simply referred to as the *FMS trajectory*.

Although the FMS trajectory theoretically can be followed from takeoff to just prior to landing, the reality is that ATC clearances during the descent and approach phase of flight often differ from what has been programmed into the FMC. Pilot reprogramming of the FMC to account for ATC clearances just prior to or during the approach is not typically performed for two reasons. First, reprogramming requires long task time, cognitive workload, and heads down time (Degani et al, 1995). Second, ATC clearances just prior to or during the approach do *not* typically require aircraft conformance to crossing restrictions (i.e., crossing a navigation fix at a certain altitude and speed). Instead, ATC clearances in this phase of flight instruct the aircraft to change heading, altitude, and speed (or any combination of the three). Hence, sophisticated guidance functions (e.g., V NAV (for vertical navigation) that are needed to follow an FMS trajectory during the climb, cruise, and descent, are not typically needed, and therefore, not engaged during the approach. Instead, much simpler guidance functions that correspond directly with ATC clearances for heading, altitude, and speed are used.

Figure 3. B757/767 flight deck

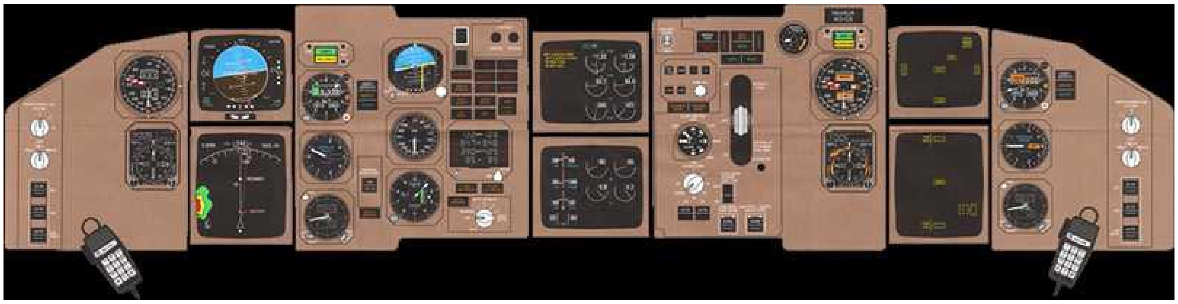

Figure 4. B757/767center instrument panel

4.4.2 Mode Control Panel

The mode control panel (MCP) is used by the pilot to select the guidance function to change the trajectory as needed. Table 1 gives an overview of these functions (adapted from Casner, 2001). The MCP allows guidance functions to be either engaged or armed. A guidance function that is engaged means that the guidance function is currently active. A guidance function that is armed means that the guidance function will engage (i.e., become active) when the required conditions for its engagement have been met. Because the guidance functions that are engaged or armed on the MCP can be difficult to decipher based on a quick glance of the MCP, a separate display, the PFD, clearly displays the roll, pitch, and thrust channels of the guidance function through what is referred to as *flight mode annunciation* (FMA). (This is discussed in more detail in Section 4.4.3)

As can be seen in the Table 1, the HEADING SELECT, ALTITUDE HOLD, and SPEED guidance functions are each dependent on only a single state – roll, pitch, and thrust, respectively. The commands for HEADING SELECT and SPEED come directly from pilot entry into the MCP. For example, if HEADING SELECT is engaged, the aircraft will begin to turn as soon as the pilot changes the heading value in the “HDG” window on the MCP (see Figure 5).

The command for ALTITUDE HOLD comes from two possible sources. In the first case, by pressing the “HOLD” button under the “ALT” window on the MCP, the aircraft will hold the current altitude indefinitely. In the second case, the altitude entered in the “ALT” window on the MCP becomes the target altitude. However, in the latter case, in order for the aircraft to change to the target altitude, FLIGHT LEVEL CHANGE must first be engaged. When FLIGHT LEVEL CHANGE is engaged, the ALTITUDE HOLD function is said to be *armed*. In this case, when the aircraft descends and reaches the target altitude, the armed condition is met and the guidance function disengages FLIGHT LEVEL CHANGE and engages ALTITUDE HOLD. In addition, the engaged pitch FMA on the PFD switches from “FLCH SPD” to “ALT” and the engaged thrust FMA on the PFD switches from “HOLD” to “SPD”. (Note that the terms *flight level* and *altitude* are used interchangeably in this context).

Another guidance function that is armed prior to being engaged is APPROACH. As an example, consider an aircraft flying with constant heading, altitude, and speed via HEADING SELECT, ALTITUDE HOLD, and SPEED functions. If APPROACH is armed, it becomes engaged when the aircraft intercepts the localizer (assuming, of course, it is on an intercept course to begin with). The engaged roll FMA switches from “HDG SEL” to “LOC”. At this point, the aircraft is commanded to fly the heading corresponding to the localizer signal. A short period of time later, the aircraft intercepts the glide slope and the engaged pitch FMA switches from “ALT” to “G S”, corresponding to aircraft commands to fly the glide slope. The thrust FMA remains unchanged, displaying “SPD”.

Table 1. B757 guidance functions for approach phase of flight

<table>
<tr><th rowspan="2">Guidance Function</th><th rowspan="2">How it works</th><th colspan="3">FMA on PFD (see Figure 6)</th></tr>
<tr><th>Roll</th><th>Pitch</th><th>Thrust</th></tr>
<tr><td>HEADING SELECT</td><td>Roll used to maintain heading dialed into “HDG” window on MCP.
1) Dial new heading</td><td>HDG SEL</td><td></td><td></td></tr>
<tr><td>ALTITUDE HOLD*</td><td>Pitch used to maintain present altitude.
1) Push altitude “HOLD” button to maintain present altitude</td><td></td><td>ALT</td><td></td></tr>
<tr><td>SPEED</td><td>Adjustments to thrust used to maintain speed dialed into “IAS/MACH” window on MCP.
1) Dial new speed
2) Push “SPD” button</td><td></td><td></td><td>SPD</td></tr>
<tr><td>LOCALIZER*</td><td>Rolled used to track dialed localizer.
1) Dial ILS course and frequency on ILS panel.
2) Arm function by pushing “LOC” button.
3) Function captures localizer.</td><td>LOC</td><td></td><td></td></tr>
<tr><td>APPROACH* (localizer + glide slope)</td><td>Roll used to track dialed localizer.
Pitch used to maintain dialed glide slope.
Adjustments to thrust used to maintain speed dialed into “IAS/MACH” window on MCP.
1) Dial ILS course and frequency on ILS panel.
2) Dial new speed (if needed).
3) Arm function by pushing “APP” button.
4) Function captures localizer or glide slope.</td><td>LOC</td><td>G S</td><td>SPD</td></tr>
<tr><td>FLIGHT LEVEL CHANGE</td><td>Thrust of engines set to idle.
Pitch used to maintain speed dialed into “IAS/MACH” window on MCP.
1) Dial new altitude
2) Dial new speed (if needed)
3) Push “FL CH” button
4) Descends to new altitude and then switches to ALTITUDE HOLD.</td><td></td><td>FLCH SPD</td><td>HOLD</td></tr>
</table>

* Guidance functions that can be armed prior to engagement

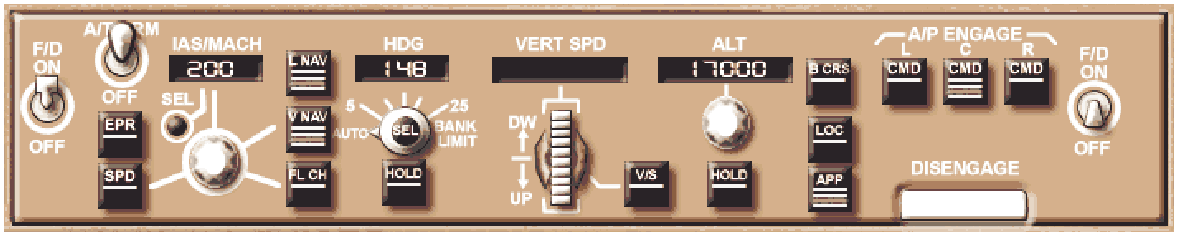

Figure 5. B757/767 Mode Control Panel

MCP description

A brief description of the MCP panel for functions used during approach is presented. Functions used in other phases of flight are not discussed here to keep it simple.

F/D – flight director for captain (far left) and first officer (FO) (far right)

ON – Allows display of Flight Director command bars on respective PFD.

OFF – Removes Flight Director from respective PFD.

A/T ARM

ARM – Arms auto throttle for engagement.

OFF – Disarms autothrottle, preventing engagement.

IAS/MACH – Speed indicator.

Speed Knob – Changes the value in the speed indicator.

SPD – Engages SPEED function.

FL CH – Engages FLIGHT LEVEL CHANGE function.

HDG – Magnetic heading indicator.

SEL Knobs – Inner knob – Changes value in heading indicator.

Outer knob – Bank limit selector .

Heading HOLD – engages HEADING HOLD(not listed in Table 1).

ALT – Altitude indicator.

Altitude Knob – Changes the value in the altitude indicator.

Altitude HOLD – Engages ALTITUDE HOLD mode manually.

LOC – Arms or engages LOCALIZER to intercept and track localizer.

APP – Arms or engages APPROACH to intercept and track both localizer and glide slope.

CMD – Engage associated autopilot in vertical speed and heading hold modes if neither flight director is on, or if either flight director is in the takeoff or go-around mode.

Disengage Bar

Up position – Allows autopilots to be engaged.

Down position – Disconnects all three autopilots from flight control servos preventing engagement of autopilots.

Figure 6. B757/767 Primary Flight Display

4.4.3 Primary Flight Display

During the approach, the PFD (also referred to as Attitude Director Indicator (ADI)) is the primary navigation instrument. Both captain and FO have a PFD. The information provided by the PFD is as follows:

Center of display

- Artificial horizon depicted by blue/black
- Transparent “aircraft wings” (outlined in white) depict current attitude of aircraft in terms of pitch and roll
- “Red cross” depicts the Flight Director (FD) command bars, which shows pitch and roll commands generated by the FMC. Typically, the autopilot or pilot rolls and pitches the aircraft to align the “aircraft wings” with the FD.

Upper left corner

- GS200 – Ground speed in knots (200 knots in this example)

Upper right corner

- DH150 – Decision height in ft entered by pilot (150 ft in this example)
- 1750 – Altitude in ft AGL provided by radio altimeter (1750 ft in this example). Note that radio altimeter makes use of the reflection of radio waves from the ground to determine the height of the aircraft above the surface.

Note: For next two groupings, words/abbreviations in green font indicate the associated mode is engaged (active). Words/abbreviations in white font indicate the associated mode is armed. The list and meaning of FMA is described in Table 1.

Lower left corner:

- A/T (in green) – this location on the display indicates autothrottle system status. In this example, the autothrottle is engaged.
- SPD (in green) – this location on the display indicates autothrottle FMA. In this example, SPD (for speed) is engaged.
- G S (in white) – this location on the display indicates *armed* pitch FMA. In this example, G S (for glide slope) is armed.
- V NAV (in green) – this location on the display indicates *engaged* pitch FMA. In this example, V NAV (for vertical navigation) is engaged.

Lower right corner:

- CMD (in green) – the autopilot/flight director status. In this example, CMD means autopilot is engaged. If FD is displayed instead, it means the flight director is engaged and autopilot is disengaged.
- LOC (in white) – this location on the display indicates *armed* roll FMA. In this example, LOC (for localizer) is armed.
- LNAV (in green) – this location on the display indicates *engaged* roll FMA. In this example, L NAV (for lateral navigation) is engaged.

Bottom center:
White dots and pink marker – localizer pointer and scale indicates localizer position with respect to aircraft. In this example, the pink indicator is right of center so the aircraft must turn to the right. This is also consistent with the flight director, which is commanding a turn to the right.

Center right:
White dots and pink marker –glide slope pointer and scale indicate glide slope position with respect to aircraft. In this example, the pink indicator is above the center mark so the aircraft is below the glide slope. This is also consistent with the flight director, which is commanding a pitch up. A term often used by pilots is *one dot below glide slope.* Note that this refers to pink indicator pointing at the first white dot *above* the center mark, but the aircraft is actually *below* the glideslope. Pilots use this indicator to configure the aircraft for the final approach. Glide slope intercept occurs shortly after.

Center left:
White dots and pink marker – fast/slow indicator depicts deviation from airspeed selected manually with the IAS/MACH selector or calculated automatically by the FMC when in V NAV. In this example, because indicator is centered, no adjustment in speed is needed.

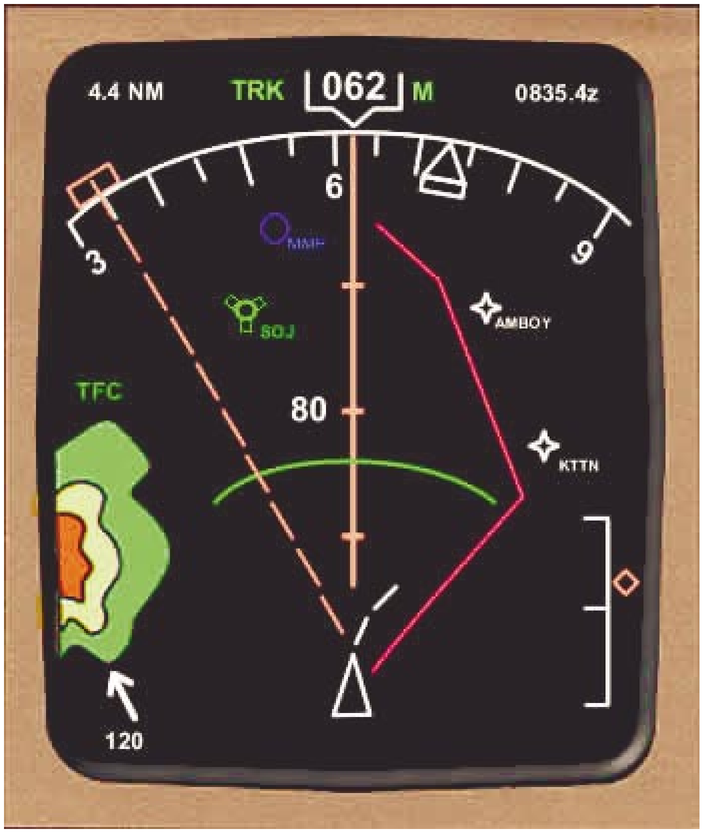

Figure 7. B757/767 Navigation Display in Map mode

4.4.4 Navigation Display

The navigation display (ND), also called the horizontal situation indicator (HSI) or LNAV display, provides a map view (see Figure 7) of the area in which the aircraft is headed. Both captain and FO have a ND. The ND can be configured in various modes with *map* mode being the most common. In fact, during approach, it is common for the ND of one of the pilots to be in map mode and the other pilot to be in *ILS* mode. ILS mode allows the raw ILS data to be displayed. Using different modes allows the pilots to crosscheck information. For example, the map mode displays information based on where the FMS thinks the aircraft is located. If the aircraft location is in error for whatever reason (e.g., a navaid has been moved, but the onboard database has not been updated to reflect the new location), there would be no way to know this from the map mode. However, if the ILS mode is being used by the other pilot and there is an ILS signal detected, then the discrepancy would become apparent by crosschecking the two displays.

ND display description

Bottom center

- White triangle – aircraft symbol. Apex of triangle indicates aircraft position relative to display.
- White dashed line – curve trend vector. Indicates predicted airplane track in 30, 60 and 90 second intervals when turning.

Center display

- “AMBOY” and “KTTN” with waypoint symbols – indicate waypoints. White for inactive, magenta for active.
- “SOJ” with VORTAC symbol – indicates VORTAC navigation aid. When NAVAID switch is ON, all appropriate navigation aids in range appear in addition to those navigation aids which are standard or active.
- “MMP” with blue circle – indicates airport. When the ARPT switch is ON, displays airports within the map area.
- “80” – Range from aircraft to associated tic. 80 nm in this example. Also indicates half of the range selected on the ND range selector. In this example, the ND range selector is set to 160 nm, displaying a moving map 160 nm in front of the aircraft.
- Magenta solid line – indicates flight plan route line.
- Pink solid line with tic marks – indicates track line based on prediction of track for present heading and wind.
- Pink dashed line – indicates the selected heading as set in the MCP. In this example, the heading is set to 35 degrees.
- Green arc – indicates altitude arc. The intersection of the green arc with either the track line or flight plan route represents the point where the aircraft will be at the altitude set in the MCP altitude indicator.

Upper left corner

- 4.4 NM – indicates distance to next waypoint in MAP or PLAN modes. 4.4 nm in this example.

Upper center

- TRK 062 M – magnetic track/heading display. 62 degrees in this example. The true heading is displayed by a white triangular pointer along the compass. In this example, the true heading is 73 degrees.

Upper right corner

- 0835.4z – indicates ETA to next waypoint in Zulu time.

Bottom right corner

- White line and tics with pink diamond – the vertical deviation indicator, which depicts the altitude deviation from the selected vertical profile.

Bottom left corner

- White arrow and “120” – the wind display. Indicates wind direction relative to map display orientation and speed (in knots). In this example, the aircraft is experiencing a 120 knot tail/side wind.
- Multicolored display – weather radar returns. Returns are presented when WXR ON switch is pushed. Highest intensity is displayed in red, lesser intensity in amber, and least intense in green. Turbulence is displayed in magenta.

Center left corner

- TFC – indicates TFC button is selected ON, which means the TCAS Traffic Display is active.

4.4.5 Traffic Alert and Collision Avoidance System

The traffic alert and collision avoidance system (TCAS) is an airborne collision avoidance system based on radar beacon signals which operates independent of ground-based equipment. TCAS generates traffic advisories, and resolution (collision avoidance) advisories in the vertical plane. TCAS is a backup system to ATC, which is the primary system for keeping aircraft safely separated.

4.5 Flight Crew

The B757, like most modern air transport carriers, is a 2-person flight deck. The crew consists of a captain and first officer. The captain and first officer are stationed in the port and starboard seats, respectively. The aircraft can be flown from either position. The person flying the aircraft is the pilot flying (PF). The other person is the pilot not flying (PNF). Air carriers have different procedures that specify which pilot should be flying the aircraft during the various phases of flight. For example, one carrier might specify that the captain fly during takeoff and the FO fly during approach and landing. Then, on the next leg of the trip, they switch so the FO flies the takeoff. This allows both pilots to maintain their skill level through all phases of flight.

5 Approach/Landing Tasks and Events

This section discusses the tasks and key decisions of the approach and landing phases of flight for the B757. The material has been obtained from flight manuals, other reports and pilot interviews. Although the information is focused on the 757, it is not specific to any airport or airline. Where applicable we have noted important task related differences associated with different airlines and different airports. The specific information presented in this section covers the following:

- A brief overview of the tasks required for approach and landing (Section 5.1).
- Detailed descriptions of each task and includes a task table and event time-line (Section 5.2).
- Description of some of the problems and errors associated with flying the approach and landing phases (Section 5.3)
- Situational awareness information requirements
- Discussion of the B747-400 simulator runs
- Cognitive decision points

5.1 Overview of Tasks

This task analysis is focused on the approach and landing phases of flight. Following the cruise phase, the crew will transition from the flight corridors to the approach area for a specific airport. The approach is essentially the portion of the flight in which the crew establishes the aircraft in the appropriate location, attitude and position to land. For both manual and automated flight, this involves incrementally slowing to landing speeds, descending to appropriate altitudes for landing and aligning the aircraft with the runway such that the landing can be executed within the appropriate runway confines. The maneuvers performed by the crew for both the approach and landing must be within the limitations of the aircraft, the procedures of the airline, the requirements of ATC, while supporting the safety and comfort of the passengers.

During the approach, the crew will make a series of speed and wing flap adjustments in order to maintain the necessary descent rate of about 300ft/mile (3 degrees) and to slow the aircraft. The minimum flap settings are a function of the weight and speed of the B757 whereas the maximum flap settings are a function of only the speed. The minimum flap setting provides the additional lift needed to keep the aircraft maneuverable at slower speeds. The maximum flap setting prevents the flaps from being damaged due to deployment at excessive speeds. Representative flap settings are given in the task table in Section 5.2.2.

The crew will also be configuring the systems, based on the type of approach to coordinate with the navigation support systems for a specific runway. In the case of an instrument approach to a CAT I runway, the configurations enable the autopilot to intercept the runway localizer and glide slope systems. In addition, the crew will be interacting with ATC as needed to get appropriate elevation, approach and landing clearances and other information and instructions. The crew will also be monitoring the systems, the progression of the flight plan, and the attitude and flight path of the aircraft. The tasks are shared (usually by established procedure) between the PF and the PNF. The primary tasks of the PF involve all aspects of the aircraft attitude, position and function. The PNF will perform necessary communications, set required altitudes, respond to requests from the PF, and double check actions of the PF. Usually, tasks of monitoring the flight control displays and ‘looking outside’ are also distributed based on visibility and distance form the airport.

For the purposes of the approach and landing task analysis, we made several basic assumptions about the aircraft and set several initial conditions for the beginning of the approach phase tasks. The following are the assumptions and initial conditions of the aircraft and flight, and a brief narrative of the approach and landing task sequence. The aircraft, passengers and baggage weigh 180,000 lbs and the associated speed and flap settings are listed with the task table. The aircraft has finished the descent phase of flight and is transitioning into the approach phase. The flight is proceeding under IMC rules towards a CAT I runway. The aircraft is approximately 11 miles from the runway threshold flying at 3000 ft AGL at 200 kts with flaps set at 5 degrees. They have intercepted the localizer and the tasks begin as they receive approach clearance.

Upon receiving the approach clearance from approach control and instructions to slow to 180 kts, the crew sets the approach mode, the speed and the flaps to 15. Once they begin to receive the glide slope signal (glide slope ‘alive’), they deploy the landing gear, reduce speed again and set the flaps to 20. Before glide slope capture (usually corresponding to what pilots refer to as “one dot below glide slope”) they again reduce speed and set flaps 25. Very shortly after this, they reduce speed again and set flaps 30 (the final flap setting) and perform the before landing checklist. Once glide slope capture has occurred, the crew sets the missed approach altitude. Upon crossing the outer marker at five miles from the runway threshold, the crew makes their final approach preparations, changes their communication radios to the tower frequency and requests a landing clearance. Upon reaching the decision height, the crew makes their final landing determination. If they cannot see the runway, they must perform a go-around. If they can see the runway, then the landing continues. If the runway is in site before the decision height is reached, the PF will often switch to manual flying prior to decision height. The point at which the crew begins to manually fly the aircraft varies with the crew but is usually associated with the ability to see the runway.

5.2 Event Timeline and Task Analysis

This section includes detailed descriptions of each task included in the event and task table. The descriptions are specific to approach and landing and the B757. They are not intended to represent similar tasks from other phases of flight or other aircraft.

5.2.1 Task Descriptions

Voice communication to ATC

When the crew communicates with ATC, it is either initiated by the crew or in response to communication from ATC. Contact initiated by the crew usually takes the form of an identification call and/or request for clearance or information. Responses usually involve reading back ATC instruction or providing requested information. Voice communication requires the crewmember to press one of the mic buttons on the yoke or on the center console and speak into their headset microphone.

Switching Radio Frequencies

The two VHF Communications control panels on the horizontal panel between the two crew members allow for two communication radio frequencies to be dialed in. A toggle switch on the panel allows the crew to switch from one preset frequency to another. During the approach, the crew will be using the approach control frequency. At or near the outer marker, the switch will be flipped to the other preset frequency which they crew would have set to the tower frequency for the airport.

Arm Approach Mode

Arming the approach mode sets up the autopilot to interact with the localizer and glide slope. If this isn't done, the aircraft will not alter its path based on information from the localizer and glide slope systems. Arming the approach mode requires pressing the approach mode button labeled APP on the Mode Control Panel (Figure 5).

Checking the Airspeed and Bug settings

Checking the airspeed requires looking at one of the two air speed indicators. The indicators include markers along the outside of the dial called bugs that are set to reference specific speeds during flight preparation or prior to descent when planning the descent and approach phases. The bug settings on the dial will let the crew know the relationship between speed and flap settings relative to the weight of the AC. The pilot flying will often ask for a speed setting relative to a bug position.

Set speed on the Mode Control Panel
Either pilot may change the speed setting on the MCP. When the autopilot is engaged, the aircraft will attempt to maneuver to attain the new speed. Setting the speed requires turning the speed mode dial until the desired speed in indicated by the digital display above the dial. Verifying that the correct speed has been entered requires looking at this display.

Flaps
The flaps may be set by either pilot but is easier from the right side seat since the flap lever is positioned to the right of the throttle controls. When used from the left seat, it requires a slightly higher level of dexterity to reach around the throttles and the flap lever position is more difficult to determine. Setting the flaps requires using one hand to move the flaps lever to the correct position and requires the operator to look at the position labels. The lever will click into a position detent for each setting. Each position is labeled. During approach and landing, the lever is periodically moved downward to the next appropriate position. Verifying the position of the flaps requires looking at the panel just to the right of the flaps lever to see which label corresponds with the location of the flaps lever. They may also use a hand to check if the lever is settled into the current position detent.

Monitoring Speed and Flaps changes
During a change in speed and/or new flaps setting, both crewmembers perform specific monitoring tasks to determine if the changes are taking the desired affect on the aircraft attitude. The PF can hear the flaps lever click into the detent for the new position. Although he will not know without looking which setting has been selected, he will know when the flaps will begin to deploy. As they deploy, both pilots can feel the change in the pitch of the aircraft and see the stall indicator change on the PFD as the pitch changes. They will both also watch the air speed indicator to determine that the air speed is changing as intended. The maneuver of slowing and setting flaps to 15 is usually consistent with attempting to intercept the glide slope. In addition to monitoring the pitch and speed change, the crew will be watching to see the glide slope indicator on the PFD (Figure 6) announce that the aircraft is beginning to intercept the glide slope referred to as ‘glide slope alive’. Following the maneuver of continuing to slow and setting flaps 30, the crew will monitor the glide slope indicator on the PFD waiting for it to indicate that the glide slope has been captured.

Landing Gear
Lowering the landing gear requires moving the landing gear lever all the way down (‘down’ for down). The lever is closer to the right seat and requires only one hand to push the lever down. If done from the left seat, it may require leaning the upper body to reach the lever. Verifying that the gear is down requires looking at the three indicator lights above the landing gear lever. They are positioned in a triangle (nose, left and right rear). If all three are green, then the landing gear is down.

Speed Brake
The speed brakes are controlled using a lever on the left side of the throttles. The lever is moved back (aft) to put out the speed brakes (or spoilers) on the wing that will ‘spoil’ the

lift of the wing and allow the aircraft to descend faster. The speed brakes also work automatically upon touchdown of all landing gear to slow the aircraft. In the forward position, the lever is in a detent indicating that the brakes are stowed. The next setting is the 'armed' position used for automatic deployment during landing. Beyond that, the lever can be moved farther back to vary the amount the spoiler panels are deployed. Verifying that the speed brakes are armed requires looking to determine that the lever position corresponds with the 'armed' label on the panel next to the lever. Verifying that the speed brakes are stowed requires looking to determine that the lever is in the forward position and using one hand to feel that it is in the detent.

Set missed approach altitude

The missed approach altitude is defined as the altitude to climb to in the event of a missed approach. The altitude is read off the approach plate while reviewing the approach procedure during the descent phase of the flight. Setting this missed approach altitude requires using the altitude knob on the Model Control Panel to dial the desired altitude.

Monitoring Altitude below 2500 ft

The display for the radio altimeter is on the PFD and is collocated with the decision height display. When altitude callouts are required below 2500 ft the crewmember making the callout will look at the radio altimeter display. This also allows the crewmember to determine how far they are from decision height.

Landing lights

The controls for the landing lights are a series of labeled switches on the middle overhead panel. Turning on a specific light or set of lights requires depressing the correct switch based on the lighting needs and associated labels.

Descent Rate

The descent rate is determined by looking at one of the two Vertical Speed Indicators which are analogue dials showing the vertical change in feet per minute.

Disengage Autopilot

The PF will turn off the autopilot when he has chosen to fly the aircraft manually. Prior to doing so, he will have both feet on the rudder pedals and place his hands on the control yoke. Once his hands are on the controls, the switch to disengage the autopilot is mounted on the outboard side of either yoke and is controlled using the thumb. An alarm will sound as the autopilot is disengaged and the PF will turn off the alarm annunciator by depressing a switch on the Mode Control Panel.

Manual Flight

Once the PF has disengaged the autopilot and taken manual control of the aircraft, his attention will be evenly distributed between looking out the window and scans of the instruments. Both hands and both feet are required to perform the tasks of manual flight. The PF will be making constant minor adjustments to maintain runway alignment, heading, speed, and sink rate using the yoke controls and rudder foot pedals. This will also require moving one hand from the yoke controls to the thrust levers for minor adjustments.

Flare
The action of flaring the aircraft brings the pitch up just slightly to cause the aircraft to settle onto the main landing gear. The PF applies back pressure to the yoke until the desired pitch is reached then feels for the contact of the main landing gear.

Monitoring Flight Path and Progress
This task is periodically performed by both crewmembers throughout all phases of flight. The task primarily involves scanning the instruments to ensure that the aircraft has not deviated from the expected path, altitude, attitude and overall flight plan. Looking at the HSI (Figure 7) allows the crew to determine if the flight path of the aircraft is along the proper heading and in accordance with the flight plan entered into the FMC. Looking at the FMA on the PFD allows the crew to determine if the aircraft is conforming to the prescribed attitude at any point during the flight and determine the configuration and functioning of the various automated flight support systems. Other displays such as the vertical speed indicator allow the crew to monitor the progress of various changes or determine that unexpected changes may be occurring.

Monitoring the Party Line
This task involves listening for communications on the frequency that is currently set. Auditory information is received through the ear piece or headphones used by the crew. The information may include specific communications from ATC directed at the crew, communications between ATC and other aircraft, or communications between aircraft. This monitoring task requires no workload when there is no communication traffic on the frequency. At such times, there is no information available to monitor. Attention is directed to the party line only when communication is initiated by the crew or when attention is drawn by communication traffic over the party line. When communication traffic does occur, the crew will quickly determine if the information is directed at them based on their call sign. They will also quickly determine if the communication is coming from ATC or another aircraft. When the communication is for the crew, they will closely attend to the information. Most communications are from ATC and involve approach and landing instructions or clearances and are expected by the crew. The crew will also monitor communications with other aircraft to the extent that they might be affected by what other aircraft are doing or how ATC is managing the airspace. ATC communications to them will either confirm their expectations of their approach and landing profile or require them to make some sort of change. Listening to communications from ATC to other aircraft or between aircraft help the crew build a mental picture of where they are in the airspace relative to the other aircraft and provide them with an idea of what to expect as they get closer to the airport.

Monitoring Aircraft Systems
This task is periodically performed by both crewmembers throughout all phases of flight. The status of any of the different aircraft systems can be checked using several different cockpit displays. Checking such displays helps the crew to determine that the aircraft systems are operating with normal tolerances and can be used to determine if a system is beginning to have a problem. The system displays include alert flags and problem

annunciators that will draw the attention of the crew when problems occur. As a result, the scan of these instruments in the absence of flags or alarms is infrequent.

5.2.2 Event and Task Table

The following table lists the sequence of tasks performed by the crew during the approach and landing. They are broken into sequences of tasks associated with specific events. Usually, the crew will perform a sequence of tasks in response to a location stimulus or communication. Each task execution sequence is usually followed by a period of monitoring as configuration settings take place or the crew weights for the next event initiator.

Each crew performs the tasks slightly differently. Often the callouts and double checks are occurring simultaneously with system setting tasks as each crewmember task performance overlap the other. As such, an overall time has been given for each sequence of tasks rather than providing individual timing information for each task. The table also lists the distribution of tasks between PF and PNF in the operator column. Each event is listed with a descriptive title and approximate aircraft position and remaining time to wheel-touch. Altitudes are given as distance AGL. Speeds are given in knots (kts). Task descriptions are either short statements of an action or, when in quotes, represent a spoken phrase. The tasks are also classified as discrete, intermittent or continuous based on the schedule of task performance. Discrete tasks are those that required single non-recurrent performance, such as activating or deactivating a system, making a setting, or stating a phrase. Intermittent functions are those that required multiple, recurrent performance such as periodically monitoring a display. Continuous tasks are those that require variable but uninterrupted performance, such as controlling aircraft heading or speed (McGuire 1991).

Initial Conditions

- Boeing 757
- 180,000 lbs
  - Speed

Speed (kts)	Min. flap settings f(weight, speed)	Max. flap settings f(speed only)
240	flaps 0	flaps 1
220	flaps 0	flaps 5
210	flaps 0	flaps 15
205	flaps 1	flaps 15
195	flaps 1	flaps 20
185	flaps 5	flaps 25
165	flaps 15	flaps 25
145	flaps 20	flaps 30
125	flaps 30	flaps 30

- Runway is ILS CAT I
- Instrument Meteorological Conditions (IMC)
- ~11 miles to runway threshold
  - ~6 miles from outer marker (OM)

- 3000 ft AGL
- 200 kts
- Flaps 5

5.2.2.1 Sequential Events and Tasks

Event / Task Description	Operator	Type
Receive Approach Clearance		
• ~3000ft AGL • 11 miles out • The ATC communication and read back take approximately 5 seconds. • Once the read back is complete, the task sequence listed for this event takes approximately 10 seconds for the crew to complete.		
ATC Communication: “You are 7 miles from the marker, cleared for approach, slow to 180”	ATC	Discrete
Read back clearance and speed	PNF	Discrete
Set approach mode	PF	Discrete
“Approach mode set”	PF	Discrete
Check airspeed	PF	Discrete
Set speed to 180	PF	Discrete
Check speed setting	PNF	Discrete
Check speed against reference bugs	PF	Discrete
Call for flaps 15	PF	Discrete
Sets flaps 15	PNF	Discrete
Responds flaps 15	PNF	Discrete
AC Attitude Adjustment Time		
• Flap deployment takes about 45 seconds to complete, after which AC is approximately 8 miles out		
Hear flap lever go into detent	Both	Discrete
Feel pitch change	Both	Continuous
Monitoring PFD	Both	Intermittent
Glide Slope Alive		
• The task sequence listed for this event takes approximately 10 seconds to complete.		
“Glide slope alive. Gear Down”	PF	Discrete
Deploy gear & “Gear”	PNF	Discrete
“Flaps 20”	PF	Discrete
Set flaps 20 & “Flaps 20”	PNF	Discrete
“Set speed bug plus 20”	PF	Discrete
Set speed	PNF	Discrete
Check speed setting	PF	Discrete
AC Attitude Adjustment Time		
• Flap deployment takes between 35 and 45 seconds to complete		
Hear flap lever go into detent	Both	Discrete

Feel pitch change	Both	Continuous
Monitoring PFD	Both	Intermittent
One Dot Below Glide Slope		
• This event begins when the glide slope bug on the PFD (Figure 6) is positioned next to the dot just above the point where the glide slope is captured. • The task sequence associated with this event takes less than 10 seconds to complete.		
“Flaps 25”	PF	Discrete
Set flaps 25 & “flaps 25”	PNF	Discrete
“Set speed bug plus 5”	PF	Discrete
Set speed	PNF	Discrete
Check speed setting	PF	Discrete
AC Attitude Adjustment Time		
• Flap deployment takes approximately 20 seconds to complete		
Hear flap lever go into detent	Both	Discrete
Feel pitch change	Both	Continuous
Monitoring PFD	Both	Intermittent
Final Flaps and Landing Checklist		
• The task sequence associated with this event takes less than 30 seconds to complete.		
“Flaps 30”	PF	Discrete
Set flaps 30 & “flaps 30”	PNF	Discrete
Call for landing checklist	PF	Discrete
Get list or starting from memory	PNF	Discrete
“Gear Down?”	PNF	Discrete
Check gear lights	Both	Discrete
“Down and checked”	PNF	Discrete
“Down and checked”	PF	Discrete
“Flaps 30?”	PNF	Discrete
Check flap settings	Both	Discrete
“Flaps 30”	PNF	Discrete
“Flaps 30”	PF	Discrete
“Speed brakes armed?”	PNF	Discrete
Check speed brakes	Both	Discrete
“Armed”	PF	Discrete
“Armed”	PNF	Discrete
Glide Slope Capture		

• ~ 6 miles out • ~130 kts • ~2.5 minutes • The task sequence associated with this event takes less than 10 seconds to complete.		
Call slide slope capture	PNF	Discrete
"Set missed approach altitude"	PF	Discrete
Sets missed approach altitude	PNF	Discrete
Cross Outer Marker		
• 5 miles out • 1500 ft AGL • 125 kts • ~2 minutes • The time associated with this task sequence can vary depending on how long it takes for ATC to respond with the landing clearance. It should take less than 45 seconds.		
Scan all instruments looking for error/warning flags	PNF	Discrete
if no flags, "Flags checked	PNF	Discrete
Switch to tower radio frequency	PNF	Discrete
Make id, location and intention call and request landing clearance	PNF	Discrete
Tower responds with landing clearance	ATC	Discrete
Read back of clearance	PNF	Discrete
Set landing light	PF	Discrete
500 Foot Call-out		
• 500ft AGL • (See Transition from Automatic to Manual Flight Event.)		
Call 500 feet, speed relative to bug and descent rate	PF	Discrete
100ft to Decision Height		
• ~300ft AGL • ~30 seconds • (See Transition from Automatic to Manual Flight Event.)		
Call out 100 feet to decision height	PF	Discrete
Cross middle marker / Decision Height		

• ~200ft AGL • ~20 seconds • The point at which the PF begins hands flying the plane could have taken place before this whenever the runway is sited (see Transition from automatic to manual flying event). • If the runway is not sited by the time decision height is reached, then they must execute a missed approach. • (See Transition from Automatic to Manual Flight Event.)		
Call out minimums at 200ft	PF	Discrete
if runway is in site, call out runway site	PF	Discrete
Hands Fly the Landing		
Looking far down runway	PF	Intermittent
Hands flying AC	PF	Continuous
Monitor instruments	PNF	Intermittent
100ft Call out		
• ~100 ft AGL • ~10 seconds		
Call out 100ft	PNF	Discrete
Flare and Wheel Touch		
• ~30 ft AGL • ~117 kts		
Flare and let AC settle onto main landing gear	PF	Discrete

5.2.2.2 Non-sequential Events and Tasks

Event / Task Description	Operator	Type
Transition from Automatic to Manual Flying		
• This event will occur once during the approach and landing phase. The PF will determine when to begin manually flying the aircraft. This is usually associated with being able to see the runway. • Once the PF begins flying manually, his attention will be out the window making sure he's aligned with the runway. The PNF will monitor the instruments and perform the required call-outs from the point where the PF began manually flight.		
Place hands and feet on aircraft control. Press autopilot disengage button. Turn off alarm.	PF	Discrete
Monitoring Flight Path and Progress		

• This task is ongoing throughout all phases of flight and consists of periodic instrument scans. The crew will periodically look at the ND display to determine that the aircraft is traveling along its assigned path and at the PFD to determine that the aircraft is at its assigned altitude and appropriate attitude. While the ND and PFD are the primary instrument displays used by the crew other instruments will occasionally be included in periodic scans.		
Monitor ND	Both	Intermittent
Monitor PFD	Both	Intermittent
Monitor other control instruments	Both	Intermittent
Monitoring the Party Line		
• This task occurs throughout all phases of flight but neither constant nor intermittent attention is required but is, instead, directed when a voice is heard over the headset.		
Monitor Headset	Both	Intermittent/ Discrete
Monitoring AC Systems		
• This task occurs throughout all phases of flight. However, while the crew will periodically scan the system displays looking for abnormalities, the aircraft systems will flag or otherwise announce system problems to direct the crew's attention.		
Monitor system displays	Both	Intermittent

5.3 Problems and Errors

Many accidents and incidents associated with the aircraft industry are related to chains or sequences of problems. Some of the problems that are part of these chains are known as latent errors that were committed or occurred either well before or early in the flight and compound or create problems later on in the flight. Although these errors and error chains are important in terms of aviation safety, the focus of this research has been on the approach and landing phases of flight. In addition, the modeling efforts that will stem from this study will focus on comparisons of equipment used primarily during approach and landing. As such, the errors discussed in this section are limited to those that can occur during the approach and landing phases of flight.

The most common errors during the approach are associated with planning and timing. One of the main differences between the 757 and other aircraft types is the difficulty in slowing down. While the wing and engine combination of the 757 allow it to fly very well, they make it harder for the crew to slow the aircraft within the limited confines of the approach phase. As a result, it is important for the crew to be particularly aware of the speed and altitude versus distance from the airport in order to prevent the common problem known as 'coming in high and fast'. As such, the crew must be planning and thinking way ‘ahead’ of the plane. Problems often occur when the crew gets ‘behind’ the aircraft such that they are rushed to get slowed and configured properly. The most common consequence of such problems is to incur a missed approach. However, the stress of time pressure can result in inattention to specific flight controls and a loss of situational awareness. Such problems have resulted in crashes or near crashes known as controlled flight into or towards terrain.

Localizer Intercept

Problems associated with intercepting the localizer stem directly from the slowing and configuration issues. If the angle is too steep or the speed too high, the autopilot will have difficulty or be unable to alter the aircraft attitude sufficiently to intercept the localizer. The aircraft must be at the localizer intercept altitude (~3000ft) and flying at approximately 200kts by the time they are within 10 miles of the airport in order to intercept the localizer properly. The speed and elevation can vary across different airports and runways. If the LOC is not intercepted then the glide slope will also not be intercepted and a missed approach will be required.

Aircraft Spacing

Spacing errors become a problem as ATC tries to prescribe aircraft locations and require maneuvers that may be difficult or impossible for the crew to perform. Problems can occur when ATC asks the crew to maintain a particular speed when they really need to be slowing or when they are asked to maintain spacing behind and aircraft they know can slow down faster than the 757. It is up to the crew to keep out of bad situations. The pilots use TCAS and information from the party line to maintain their awareness and spacing from other AC. The results of errors can be illegal spacing between aircraft or coming in ‘high and fast’. Both these situations can incur a missed approach.

Stabilization Gates

The crew must be able to hit particular stabilization gates. That is, at certain locations during the approach, the crew must have achieved a certain attitude and speed in order to continue the approach. By 1,000 ft AGL the speed, sink rate and alignment suitable for landing ‘should’ be achieved. If the aircraft is not stable at a speed of about 130 kts, a sink rate of about 700 ft per minute and properly aligned within the localizer or in visual contact with the runway then a missed approach is mandatory. The airspeed varies a little with landing weight and the groundspeed will vary some with the wind. Sink rate can vary somewhat with groundspeed. Some airlines require stabilization by 1000ft while others require it at 500ft. Many pilots use the general rule of 1000ft if they are having trouble stabilizing the aircraft for final approach.

Speed Brakes

For each of the last three problem areas there is some help on the 757. If the pilot flying finds that they are coming in too high and/or fast, he has the option to use the speed brakes. On all aircraft the speed brakes (or spoilers) are flaps on top of the wing. When they are deployed they lift up and not only catch air to slow the plane down but also destroy the lift created by the wing allowing the aircraft to lose altitude. On the 757 the use of the speed brakes is part of the standard procedure during approach and landing. The pilot flying can deploy the speed brakes for a short period to help the autopilot achieve a necessary altitude and/or speed requirement. While the use of the speed brake is common practice for the 757 there are also problems associated with its use. The primary error is to forget that they are deployed and try to land. They will induce a high sink rate and increased deceleration that the autopilot and auto throttle may try to make up for. In addition, if the speed brakes are deployed during landing, a tail strike is likely to occur upon flaring the aircraft.

<u>FMC Reprogramming</u>

Another problem relates to the reprogramming of the FMC. Due to weather or other concerns, the ATC may change the approach plan expected and programmed into FMC by the crew. Such changes can occur at any point during the flight and can be a common occurrence at crowded airports. If a change is made, the crew will want to reprogram the FMC to reflect the new flight plan. The general rule is that you should not attempt to reprogram an approach if you are below 10,000ft. The problem is that there may not be enough time to make the changes and still perform the necessary slowing and configuration tasks. In addition, the attention of the crewmember working with the FMC is directed down and away from other instruments and the cockpit windows. This can translate to errors of attention in which the crew fail to monitor course changes or aren't able to achieve a proper stabilization gate.

<u>Radio Frequency</u>

Approach frequency errors of the communication and navigation radios can also occur. This happens usually as a result of haste, the failure of a second check, or through slips and the flipping of digits. Such errors are usually caught with sufficient crew resource management practices. Also, if two navigation radios are set to mismatched frequencies then warning flags will alert the crew. However if both crewmembers fail to set the radios or make appropriate changes there are no flags to alert them to the problem. Unlike the navigation radios, there are no alarms for the communication radios. Usually, upon tuning a radio or flipping the frequency setting switch, the crew will initiate a call or hear other communication. If no communication is heard or there is no response, the crew will return to the previous frequency (approach control) to get frequency clarification. The consequences of errors setting the communication radios can range from simply not getting the information required to reach a stabilization gate thus incurring a missed approach or more serious issues of spacing in heavy traffic patterns. Consequences of errors setting the navigation radio frequencies can result in failing to capture the localizer and incurring a missed approach.

<u>Distractions</u>

Distractions are not uncommon during flight. There are many things that can divert the crew's attention from a current task. Some of these are events or issues that must be attended to while others can represent simple nuisances. If a pilot becomes distracted, he may or may not remember to return to the task he was performing or may not be able to complete it in a timely manner. Other distractions may function as performance shaping factors that make normal tasks more difficult. Changes made by ATC to the flight plan can become distractions. This is especially true if the aircraft is close to the airport and the crew has to make changes either to the FMC and/or to their own awareness and planning during an already busy phase of flight. A high volume of communication traffic on the party line can distract the crew from other tasks as they attempt to comprehend all the information that is being presented. Periods of high air traffic associated with the approach phase at busy airports will also provide distractions as the crew attempts to maintain visual contact and spacing from aircraft near by. Weather can actually cause more distractions when it is minor. Serious weather that limits visibility we result in a change in the aircraft spacing rules and runways that are used. However, light weather that is on the edge of VFR conditions may make it difficult to carry out expected visual tasks such as identifying other nearby aircraft. Likewise, approaches and landings done at night over large brightly lit areas can make it difficult to see lights of other aircraft and the airport as their identifying lights are lost in the high light background. Finally, equipment problems or failures can represent serious distractions depending on the system, severity of the problem, and phase of flight.

5.4 Information Requirements and Situational Awareness

A large portion of the commercial pilot's time during flight is associated with maintaining and updating an accurate mental picture of where the aircraft is, how the flight is progressing relative to the flight plan and predicting how changes will affect the position of the aircraft later on in the flight. It is this situational awareness that forms the basis for decision-making during flight. The airline industry recognizes the importance of situational awareness (SA) as part of flight safety and has expended great effort to train and teach SA and decision making skills as part of regular pilot training. In addition, a number of studies have focused on SA and information requirements of commercial pilots during flight. As part of this research, we reviewed three studies focused on information requirements for SA and decision making during different phases of flight.

The first two studies (Ververs 1998 & Schvaneveldt, 2000) both focused on the relative importance of information during different phases of flight. In both cases, pilots were provided with a survey that included a list of common information available during flight. The pilots were asked to rank the relative importance of each piece of information across different phases of flight. Both studies covered the approach and landing phases and both studies exhibit similar results in terms of what pilots thought were the most important cues.

The third study (Endsley 1998) attempted to create an exhaustive list of every type of information desired by pilots to generate complete and accurate SA throughout an entire flight. The requirements were based on the goals and decisions that pilots make throughout each phase of flight. The result is a highly detailed list of SA information requirements for each of the three levels of SA; perception, comprehension and projection, included in Endsley's taxonomy of situational awareness. This list is combined with the goal and decision analysis to create a table that describes all the SA requirements for each goal and decision made throughout a flight. The information list was generated based on pilot interviews and includes all the possible information that pilots would like to have. The study was focused on generating this list to help future cockpit designers and points out that some of this information desired by the pilots is not provided by current cockpit systems. In addition, the study recognizes that while some SA of all information elements is required, some elements are more important than others during different phases of flight. However, there is no attempt to prioritize this information as was done in the other two studies.

Since we were able to find these three studies, we chose not to specifically elicit information requirements during the pilot interviews. It seems that these studies should provide SA information requirements and pilot decisions sufficient for the purposes of the modeling teams. We initially attempted to establish links between the SA elements and decisions from these studies and the flight tasks described in this study. Although it seemed possible to determine such associations, we found that in order to do so we needed to make assumptions about how the information would be used within the modeling environments. For example, SA elements from Endsley's 2nd and 3rd SA levels (comprehension and projection) require a variety of SA elements from the first level (perception). There are a number of ways to analyze and represent this information based on how the modelers might choose to use it. We decided that such decisions were best left up to the individual modeling teams and so we have chosen to include the three studies in our list of recommended reading.

5.5 B747-400 Simulator Scenarios

Simulator runs for nine approaches to San Francisco were conducted in the B747-400 full motion simulator at NASA Ames on Feb. 14, 2002. A retired United Airlines 747-400 captain was in the captain's seat. An active Delta 757/767 captain was in the FO's seat. The Delta pilot had never flown a 747 before, either in the real world or in a simulator.

Simulation plan

Aircraft control

- Manual (Flight director on)
- Coupled (Flight director on, autopilot on, autothrottle on) to decision height and then switch to manual

Winds 235 deg (from SW)

ATC communication was simplified for all of the runs. There was no party line activity between ATC and other aircraft that the pilots could monitor.

Initial conditions for Runs 1 - 6.

Level flight at 2000 ft MSL
Heading 312 degrees
Speed 200 knots indicated airspeed (KIAS)
Approximately 12 nm from runway
About 3 nm left from runway 28 Right localizer on a 30 degree intercept
Landing gear up
Flaps at 5 deg
Category I ILS 28R approach procedures:

GSIA 1800 ft
Outer marker to touchdown zone 5.3 nm

Decision height 211 ft MSL, 200 ft AGL
Glide slope 3 deg, localizer course 282 deg

Modifications to initial conditions for Run 7
Heading 221 degrees
About 3 nm left from runway 19 Left localizer on a 30 degree intercept.
Category I ILS 19L approach procedures:
GSIA 2900 ft (note sim conditions start aircraft below GSIA so glide slope intercept occurs later in the sim than in the real world)
Outer marker to touchdown zone 5.1 nm
Decision height 208 ft MSL, 200 ft AGL
Glide slope 2.95 deg

Modifications to initial conditions for Run 8 - 9
Heading 161 degrees
About 3 nm right from runway 19 Left localizer on a 30 degree intercept.

Scenarios for 747-400 simulator

Run #	Approach	Visibility: What pilots were briefed	Visibility: What was simulated*	Control mode	ATC script
1	ILS 28R	VMC	VMC	Coupled	Nominal
2	ILS 28R	VMC	VMC	Manual	Late runway change, sidestep to 28L
3	ILS 28R	CAT I	400 x 2	Coupled	Nominal
4	ILS 28R	CAT I	0 x 0	Manual	Nominal
5	ILS 28R	CAT I	400 x 2	Coupled	Early reassignment to 28L
6	ILS 28R	VMC	VMC	Manual	Early reassignment & vector to 19L
7	ILS 19L	CAT I	0 x 0	Coupled	Nominal
8	ILS 19L	CAT I	400 x 2	Coupled	Nominal
9	ILS 19L	VMC at night	VMC at night	Coupled	Late runway change, sidestep to 19R

* 1st number is cloud ceiling in ft, 2nd number is visibility at the runway in miles. For example, 400 x 2 means 400 ft ceiling with 2 miles of visibility

Run 1
The first run was an introduction for the FO to the B747-400 flight deck. The captain was the PF, but he assumed radio communication responsibility for this run to allow the FO to become familiar with the differences between the 757 and 747. The run was a straight forward approach and landing. Aircraft slowing and configuration of the proper flap settings were performed nominally.

ATC clearances were as follows. Words in brackets [] added by the authors for clarification:

About 15 seconds into the run:
NASA 31, bay [area] approach [control], 5 miles from BRIJJ [outer marker], maintain 2000 [ft MSL] until established on localizer, cleared for ILS runway 28 Right [approach].

Shortly after glide slope intercept:
Winds [from] two three five [235 degrees] at one five [15 knots], gusting to two zero [20 knots], cleared to land 28 Right.

No significant decision points were encountered on this run. The PF switched to manual mode at decision height, which is a basic procedure for coupled approaches. However, since the pilot had the runway in sight well before decision height, he could very well have switched to manual mode earlier. After the switch to manual, the 20 knot gusting crosswind required most of the pilots attention to keep the aircraft aligned with the centerline during the last 30 seconds or so until touchdown. In fact, the autopilot and autothrottle were observed to provide better performance keeping the aircraft aligned with the localizer/glide slope as compared to manual mode.

One item of interest was that the sim initial conditions placed the aircraft on the localizer intercept very near to the glide slope intercept. If the localizer intercept heading failed to intercept the localizer (i.e., intercept heading too shallow), the aircraft could start to descend on the glide slope without establishing lateral course guidance. This could potentially be dangerous because terrain and obstacles such as high tower antennas may be in the vicinity. One way to prevent this from occurring is for the pilot to arm the LOCALIZER first. When the LOCALIZER engages, the pilot then arms the APPROACH. This inhibits the aircraft from descending on the glide slope until lateral course guidance, via the localizer, is established.

Run 2

Approach	Visibility		Control mode	ATC script
	What pilots were briefed	What was simulated		
ILS 28R	VMC	VMC	Manual	Late runway change, sidestep to 28L

Again, the captain was the PF. Two interesting human performance issues were identified. The first was an issue related to manual flying. In manual mode (in this case the autopilot was off, but the autothrottle was on), the gusting crosswinds resulted in a very significant amount of the PF's attention to stay aligned with the localizer and glide slope. This is in sharp contrast to Run 1, which had the autopilot engaged until decision height. When the runway centerline was visible, the PF estimated that 80% of the time he was looking out the window to stay aligned with the centerline. As part of crew resource management, if the PF is looking out the window, the PNF focuses his attention on the instruments for speed, altitude, glide slope and localizer alignment, calling out important events as required.

The second issue was with respect to the clearance from ATC to sidestep to the parallel runway 28 Left, which occurred about a minute before landing. ATC issued the clearance:

NASA 31, sidestep from runway 28R to runway 28L, disabled aircraft blocking runway.

The PF had a short period of time to decide if the sidestep clearance was feasible. If the PF had any reservations about the safety of the clearance, he could have declined the clearance and executed a missed approach instead. In this scenario, the PF could see runways and VASI lights, and knew there was no other traffic nearby so he accepted the clearance and easily maneuvered to 28L. Meanwhile, the PNF was trying, but unable to tune the 28L ILS. Instead, 28R remained tuned, which caused the flight director to continue to provide guidance on the PFD to 28R. The PNF notified the PF of the problem. From this point forward, the PF ignored the flight director completely, using the VASI lights for vertical guidance and the runway centerline for horizontal guidance.

Run 3

Approach	Visibility		Control mode	ATC script
	What pilots were briefed	What was simulated		
ILS 28R	CAT I	400 x 2	Coupled	Nominal

Again, the captain was the PF. This run can be described as a by-the-book ILS approach in Category I conditions. Because Run 1 and Run 3 were both coupled approaches, the flight path flown by the aircraft was essentially identical for the two runs. The big difference was the pilots couldn't see anything out of the window in Run 3 until 400 ft. This meant the pilots had no out-the-window cues for crosschecking. The PF was watching to ensure the aircraft was aligned with the glide slope and localizer. The PNF was monitoring and crosschecking instruments, in particular altitude, and occasionally checking localizer and glide slope. As the aircraft approached 400 ft MSL, the ceiling reported to them, both pilots began to look out the window for signs that the clouds were breaking up, but the PF was also checking the instruments as well. As the aircraft broke through the clouds at 400 ft, both pilots were looking to see if the runway was visible. When they could see the runway, the PF declared "runway in sight" and turned much of his attention out the window, whereas the PNF monitored instruments, primarily for altitude and speed.

Run 4

Approach	Visibility		Control mode	ATC script
	What pilots were briefed	What was simulated		
ILS 28R	CAT I	0 x 0	Manual	Nominal

The FO was the PF for the first time in the sim sequence. The same conditions were reported as Run 3. The PF was in manual mode and just like Run 2, gusting crosswinds resulted in a very significant amount of the PF's attention to stay aligned with the localizer and glide slope. As they approached decision height, there was no indication that the clouds were breaking up so the expectation of executing a missed approach was high. As they reached decision height and still no break up of clouds indicated, PF stated he was executing a missed approach. Since the autopilot was disengaged, the PF had to initially climb to the missed approach altitude in manual mode. If the autopilot had been engaged, he could have executed the missed approach in autopilot mode simply by hitting the go around button on the throttle.

Run 5

Approach	Visibility		Control mode	ATC script
	What pilots were briefed	What was simulated		
ILS 28R	CAT I	400 x 2	Coupled	Early reassignment to 28L

The captain was the PF. This run involved an ATC-directed reassignment to 28L. Because this happened so early in the approach, the captain requested that the FO enter the ILS 28L approach into the FMS. Reprogramming the FMS is a time consuming, heads down task that effectively takes the PNF out of the loop from all other tasks. In this scenario, the FO took 50 s to reprogram the new approach. This is probably longer than would normally be the case, due to the fact that the 747 CDU is slightly different from the 757 CDU (remember that the FO is 757 pilot). However, it is clearly a task that the pilots would not undertake during final approach. Other than the initial reprogramming effort, the rest of Run 5 was nearly identical to Run 3.

Run 6

Approach	Visibility		Control mode	ATC script
	What pilots were briefed	What was simulated		
ILS 28R	VMC	VMC	Manual	Early reassignment & vector to 19L

The FO was the PF. Shortly after the landing gear was down, ATC delivered the following clearance:

NASA 31, cancel approach clearance, climb and maintain 3000, expect ILS approach runway 19L, localizer 108.9.

And then a few seconds later:

Turn right heading 010, maintain 3000.

The PNF used the HEADING SELECT and FLIGHT LEVEL CHANGE guidance functions to execute the clearance, dialing the appropriate numbers into the MCP. The PNF then set the flaps to 20 and retracted the landing gear. The PF was in manual mode so much of his effort was focused on using the control yoke to follow the flight director. During the few minutes required to fly the downwind leg, the PNF tuned ILS 19L signal and then briefed aloud the ILS 19L approach and missed approach procedures.

After sufficient distance on the downwind leg, ATC directed:

NASA 31, turn left heading 270, maintain 3000, speed of 170 or less.

Before this turn was completed, came another message:

NASA 31, continue left heading 220, 3 miles from SHAKE, 3000 until established, cleared ILS 19L

After the PNF dialed in the new heading, the aircraft was back on a nominal ILS approach. The PNF positioned the auto-brakes to a higher setting of 3 to account for the shorter runway (8,900 ft for ILS 19L vs. 11,870 ft for ILS 28R).

Run 7

Approach	Visibility		Control mode	ATC script
	What pilots were briefed	What was simulated		
ILS 19L	CAT I	0 x 0	Coupled	Nominal

The captain was the PF. At the 400 ft reported ceiling height, there was no sign of the clouds breaking up. At decision height, the PF decided to go around. The autopilot was engaged, which allowed the PF to push the go around button on the throttle to automatically begin the missed approach. The autopilot controlled the pitch and roll to climb the aircraft to missed approach altitude and heading dialed into the MCP while the autothrottle provided the go around thrust.

Run 8

Approach	Visibility		Control mode	ATC script
	What pilots were briefed	What was simulated*		
ILS 19L	CAT I	400 x 2	Coupled	Nominal

The FO was the PF. A straight forward Cat I ILS approach for the most part. The center autopilot disengaged during the initial approach segment (not sure if the sim person scripted this, or it disengaged on its own). The PNF engaged the left autopilot (autopilot is really three redundant systems). The autopilot stayed engaged until it was manually disengaged by the PF at decision height.

Run 9

Approach	Visibility		Control mode	ATC script
	What pilots were briefed	What was simulated*		
ILS 19L	VMC at night	VMC at night	Coupled	Late runway change, sidestep to 19R

The captain was the PF. This was the only run to occur at night. Similar in some respects to Run 2. Once again, the center autopilot disengaged so the right autopilot was engaged by the PNF. ATC directed a sidestep late in the approach. The PF accepted the clearance and flew manually without the flight director. Since 19R has no ILS, there was nothing for the PNF to tune to for localizer or glide slope, but the VASI lights and runway centerline were clearly visible. 19R (7000 ft long) is almost 2000 ft shorter than 19L. In the real world, a 747 would not have been directed to this runway, but in the sim world it was fair game. The captain positioned the auto-brakes to a setting of 4. The aircraft came to a stop very close to the end of the runway.

5.6 Cognitive Decision Points

The previous section introduced some practical examples of decision making that the pilots must address. In this section, a summary of the key decision points during the approach and landing will be discussed.

5.6.1 Missed Approach

The decision to execute a missed approach could be caused by any of the following:

1. ATC-directed
2. Too high on glide slope
3. Too low on glide slope
4. Too far left or right of the extended runway centerline
5. Too fast
6. Failure to see the runway at decision height because of poor visibility
7. Other weather-related events

ATC-directed

An ATC-directed missed approach is of little interest to this research because it is completely out of the hands of the pilots. ATC directs the pilots to execute a missed approach and they comply – not much to understand there.

Too high on glide slope

If the aircraft is too high on the glide slope, the aircraft could overshoot the runway. As the aircraft approaches decision height, the decision to continue the landing involves evaluating several elements:

Quantitative factors:

- How high above glide slope am I?
- Where do I think I can safely touch down based on where I’m at now?
- How much runway do I need once I touchdown?
- How much will the runway provide?
    - How long is it?
    - Or, do I have to land and hold short of an intersecting runway?

- What are the conditions on the surface of the runway (ice, snow, water, worms [yes, nightcrawlers invaded the runways of Cleveland airport after a couple of days of rain])?
- Are my aircraft systems operational (brakes, thrust reversers)?
- How much fuel do I have (might not have enough fuel for a 20 minute missed approach)?
- How heavy am I (an empty airplane stops very quickly)?

Qualitative factors that may weight decision to continue with descent

- Maintaining schedule
- Passengers with missed connections
- I want to get home/get off this plane

With a strong emphasis on safety, if any of the quantitative factors clearly indicated that a landing would be unsafe, the pilots would execute a missed approach. In addition, the pilots would not need to wait until decision height to do so – they can execute a missed approach at any point in the final approach. If the quantitative factors do not make the decision black or white, one would expect that the qualitative factors might come into play.

Too low on glide slope
If the aircraft is too low on the glide slope, the aircraft could hit the ground prior to the runway threshold. The decision to continue the landing involves the same qualitative factors as the "too high" case, but fewer quantitative factors:

Quantitative factors:

- How far below glide slope am I?
- If I continue the descent at the same rate, where will the aircraft touchdown?
- How much should I adjust the descent rate to get me *safely* over the runway threshold?
- How much fuel do I have (might not have enough fuel for a 20 minute missed approach)

Too far left or right of extended runway centerline
If the aircraft is too far left or right, the aircraft could miss the runway or land on the runway, but then skid/roll off of it. The decision to continue the landing involves similar qualitative factors as the other cases, but fewer quantitative:

- Can I align the aircraft with the runway centerline in the amount of time left until touchdown?
- How much fuel do I have?

Too fast
The kinetic energy of an aircraft is proportional to its speed squared. Hence, if a pilot is coming in 20% faster than nominal, the braking energy to slow the aircraft down will be 40% higher than nominal. Because of this, pilots are very concerned with their speed, particularly on airports with short runways to begin with.

- How much runway do I need once I touchdown?

- How much will the runway provide?
    - How long is it?
    - Or, do I have to land and hold short of an intersecting runway?
- What are the conditions on the surface of the runway?
- Are my aircraft systems operational?
- How much fuel do I have?
- How heavy is my aircraft?

Failure to see the runway at decision height because of poor visibility
Background info: The pilots must be able to see the runway at decision height for Cat I approaches because the ILS signal is not being protected at the highest level (as it is for Cat III autoland). This means that the ILS signal may have some interference that can have the effect of taking the aircraft off course. Early in the final approach, this interference could be easily corrected, but at decision height there is not ample time to make any corrections. Hence, a visual reference (i.e., the runway) is needed to confirm that the aircraft is aligned. If the runway is spotted and the aircraft is not aligned (too high, too low, etc.) one of the other decisions listed above comes into play. Until the runway is spotted though, the following elements are considered by the pilot:

- The pilots have already received a report of the cloud ceiling altitude.
- As the aircraft approaches the ceiling altitude, the pilots have an expectation of seeing the clouds begin to break up.
- Below the ceiling altitude, but above decision height:
    - If there is no indication that the clouds are breaking up, the pilots mentally prepare for a missed approach.
    - If the clouds are starting to break up, the pilots plan to continue with the descent.
- Just prior to decision height:
    - The pilots are looking for any changes in visibility to reaffirm or disprove their earlier predisposition to:
        - continue the landing (most likely the runway is in sight by this time).
        - execute a missed approach (most likely the runway will not appear).
- At decision height, unless something very unusual happens (e.g., the aircraft punches through a very well-defined cloud layer instantaneously), the pilots have already made their decision and react accordingly.

Other weather-related events
Wind shear and micro-bursts are other weather related events that can cause missed approaches. Pilots know these conditions are out of their control so they are likely to be very conservative with their decision to continue the descent. Pilots are trained to understand, and the system itself supports it, that any missed approach, regardless of the circumstances, will not reflect negatively on their skills or abilities.

5.6.2 Controlling Speed

Controlling speed is not a single *decision point* per se because the need to control speed is often required throughout the approach. Controlling speed is a more difficult task for the 757 during approach compared to other air transports because of its very good glide performance (high lift over drag). Whereas the autothrottle can automatically increase thrust if additional speed is needed, there is no *automatic* equivalent for slowing an aircraft down. For quick deceleration, the good glide performance precludes just setting the engines to idle, particularly when the aircraft is descending anyway. The speed brake can be used manually to slow down the aircraft, but it is against procedures to use the speed brake during the final approach (the speed brake out during landing has caused accidents and certainly would result in a tail strike). Furthermore, although the flaps provide additional drag, the flap extension is a function of airspeed – they cannot be deployed at high speeds because it will damage them. Another tool for slowing the aircraft down is to extend the landing gear earlier in the approach phase since the landing gear adds considerable drag to the aircraft. What is important here is to emphasize that the pilots must focus on reducing speed as early in the approach as possible.

Sometimes though this is easier said than done. For example, consider the descent-to-approach transition where ATC has seven aircraft lined up. If the situation exists that the back six aircraft are properly spaced, but the distance between the first and second is too close, then it is much easier for ATC to instruct the first aircraft to speed up to increase its spacing from the second aircraft. This saves the controller from having to instruct the other six aircraft to slow down, significantly reducing his/her workload. Thus, even if the 757 pilot wants to slow down early, it is not always possible.

6 Recommended Reading

Fundamentals of Air Traffic Control by M. Nolan
Provides an excellent description of ILS, instrument approach procedures, runway lighting, and ATC communication phraseology.

An Exploration of Function Analysis and Function Allocation in the Commercial Flight Domain, by J. McGuire et al of Douglas Aircraft (over 300 pages!)
Provides a very detailed functional analysis for a flight from LA to NY. Excellent source for event timeline information.

Key Cognitive Issues in the Design of Electronic Displays of Instrument Approach Procedure Charts, Monterey Technologies.
The main document doesn’t apply specifically to HPM of the approach, but it has a very interesting 34 page appendix, which actually includes a Conceptual Graph Structure of the ILS approach. Also contains a high-level task analysis.

The Boeing 757/767 Simulator and Checkride Procedures Manual by M. Ray
This “unofficial” manual provides excellent insight into recovering from off-nominal events or conditions, and highlights the key items to remember to stay out of trouble in the first place.

The Pilot's Guide to the Modern Airline Cockpit by S. Casner.
Hot-off-the-press, this "technical, but doesn't read that way" book explains very clearly the next generation flight deck with an emphasis on the FMS and guidance modes.

Situation Awareness Requirements for Commercial Airline Pilots by M. Endsley et al.
This paper breaks SA requirements down by phase of flight
(included to modelers electronically)

Priority and Organization of Information Accessed by Pilots in Various Phases of Flight by Schvaneveldt et al.
Provides insight into what information is most important to pilots, decomposed by flight phase.
(included to modelers electronically)

Understanding a Pilot's Tasks by P. Ververs.
Similar to above, with a slightly different emphasis
(included to modelers electronically)

7 Acknowledgements

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8 Acronyms

ADI	Attitude Display Indicator
AGL	Above Ground Level
ATC	Air Traffic Control
AvSP	Aviation Safety Program
CDU	Control Display Unit
FAF	Final Approach Fix
FD	Flight Director
FMC	Flight Management Computer
FMS	Flight Management System
FO	First Officer
GSIA	Glide slope intercept altitude
HPM	Human Performance Modeling
HSI	Horizontal Situation Indicator
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
KIAS	Knots Indicated Air Speed
Kts	Knots
LNAV	Lateral Navigation
MCP	Mode Control Panel
ND	Navigation Display
OM	Outer Marker
PF	Pilot Flying
PFD	Primary Flight Display
PNF	Pilot Not Flying
SA	Situation Awareness
SME	Subject Matter Expert
STAR	Standard Terminal Arrival Route
SVS	Synthetic Vision System
TCAS	Traffic alert and Collision Avoidance System
VASI	Visual Approach Slope Indicator
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation

9 References

Alter, K. W. and Regal, D. M., (1992). Definition of the 2005 Flight Deck Environment, NASA Contractor Report 4479.

Casner, S. (20010. The Pilot's Guide to the Modern Airline Cockpit, Iowa State University Press, Ames, Iowa.

Clay, M. (1993). Key Cognitive Issues in the Design of Electronic Displays of Instrument Approach Procedure Charts, Monterey Technologies. DOT/FAA/RD-93/39. NTIS #PB94-141991.

Degani, A., Mitchell, C. M., and Chappel, A. R. (1995). Task Models to Guide Analysis: Use of the Operator Function Model to Represent Mode Transition, Proceedings of the Eighth International Symposium on Aviation Psychology.

Endsley, M. R., Farley, T. C., Jones, W. M., Midkiff, A. H., and Hansman, R. J. (1998). Situation awareness requirements for commercial airline pilots. International Center for Air Transportation, Massachusetts Institute of Technology, Cambridge, MA, 02139.

McGuire, J. C., Zich, J. A., Goins, R.T., Erickson, J. B., Dwyer, J. P., Cody, W. J., and Rouse, W. B. (1991). An Exploration of Function Analysis and Function Allocation in the Commercial Flight Domain, NASA Contractor Report 4374.

Nolan, M. (1994). Fundamentals of Air Traffic Control, Wadsworth Publishing Company, Belmont, CA.

Ray, M. (2001) The Boeing 757/767 Simulator and Checkride Procedures Manual, University of Temecula Press, Temecula, CA.

Schvaneveldt, R.W., Beringer, D.B, and Lamonica, J.A. (2000). Priority and Organization of Information Accessed by Pilots in Various Phases of Flight. The International Journal of Aviation Psychology, 11(3), 253-280.

Ververs, P.M (1998), Understanding a Pilot's Tasks. University of Illinois, Aviation Research Laboratory, Savoy, IL.

A Appendix A - Example incidents and accidents on approach to landing

The effort to develop realistic models of cognitive performance would be well served to consider actual incidents and accidents in which human error was causal. These examples could serve as a template for the design of high fidelity discrete event models of aircrew in sophisticated 'glass cockpit' and fly by wire aircraft. In spite of the advanced electronic flight deck of these aircraft or perhaps in confused concert with them, accidents have happened that were unforeseen by engineers and instructors and which often become valuable lessons for future crews. There is an axiom in aviation instruction that demonstrates how clever humans can be in finding ways to make incorrect decisions which states that "truth is always stranger than fiction because fiction has to make sense". The following are detail ed examples of commercial aircraft tragedies that demonstrate how error chains can develop leading to incorrect decisions often with fatal consequences.

- The Incidents and Accidents
  - China Airlines Airbus A300 in Taipei (*1998*)
  - The Korean Air Lines B747 CFIT Accident in Guam (*1997*)
  - The American Airlines B757 Accident in Cali (*1995*)
  - The A300 Crash in Nagoya (*1994*)

1.1 China Airlines Airbus A300 crash in Taipei (1998)

On Monday 16 February, 1998, at approximately 20:09 local time, China Airlines Flight 676 from Bali, an Airbus A300, crashed into a residential area during an ILS/DME Rwy 05L approach to Chiang Kai Shek International Airport near Taipei, Taiwan. The event occurred under conditions of darkness with rain and reduced visibility due to fog. All 15 crew and 182 passengers were killed. At least 7 additional people were killed on the ground.

Initial Conditions

The aircraft appeared to be very high on the approach glide slope. At some point near the runway threshold, where the aircraft is still at well over 1000ft altitude, it climbs steeply, evidently stalls, and crashes 2 miles past the runway threshold. The Outer Marker/Final Approach Fix is at approximately 3.9nm (nautical miles, = 4.5 statute miles) from the runway threshold. The Outer Marker is at 4.1DME from the localizer. This means that the DME is located (with the localizer) about 0.2nm beyond the runway threshold. At 140kts ground speed, the time from FAF to Missed Approach Point (MAP) is 1min 40sec. The approach altitude is 3000ft until established on the ILS. The ILS glide slope is 3°, inbound course 053° magnetic heading (magnetic variation is 3° West). Runway threshold elevation is 73ft MSL. Crossing altitude at the Outer Marker is 1400ft MSL (Ladkin, 1998). Decision Altitude is 275 ft QNH (QNH = with altimeter setting for MSL); the Runway Visual Range (RVR) requirement is 600 meters. The Category II - ILS ceiling minimum would be 100ft QFE. The airport is on flattish land close to the ocean, which lies a couple of nautical miles (nm) away to the northwest. All three runways are north-east/south-west oriented, between 50 and 60 degrees North, and lie approximately parallel to the shoreline.

All maneuvering for approaches and missed approaches takes place over the ocean. Higher terrain, rising to 2000 feet, lies 5-8 miles east, and 5-12 miles south. There is terrain to 2,400 feet about 11nm east, and terrain to 4,000 feet some 13-15 nm south-southeast. On the night of the crash, visibility was extremely bad. The pilot said he was having trouble seeing the runway as he made his approach and asked to come around for another try. Captain Lin Kang Long was 49 years old and had 7,210 hours total flight time. First Officer Jiang Der-Sheng was 44 years old and had 3,530 hours total flight time. Both pilots were formerly with the Taiwanese Air Force.

Sequence of Events

The pilot was performing an ILS/DME approach to runway 5L at Chiang Kai Shek International, Taipei, Taiwan at night in rain and fog.

Sequence of Events Table

Time	Speed	Altitude	Pitch	Bank	Comments
	(kts)	(ft MSL)			
20h03m13s	187	3187			Flaps 15°. Engines idle.
20h03m46s	185	2483			Flaps 20°. At the Outer Marker.
20h03m55s					CAL676: "*Tower CAL676, 3 mi. on final*".
20h04m00s					TWR: "*CAL676 cleared to land, wind 360 at 3*".
20h04m30s	decreasing	1515			1,000 ft too high on glideslope, 1.2nm to touchdown. Elevator angle decreases and fluctuates.
20h04m40s		1395	0°.		
20h04m43s	167	1339			Flaps 40°. 0.5nm to threshold.
20h04m46s	159	1323	increasing		Minimum altitude of the flight.
20h04m50s	149	1375			Autopilot disconnected. 0.20nm to threshold.
20h04m59s		1475			Go-around thrust. Engine rpm increases. At threshold.
20h05m04s	150	1480	19.52°.		
20h05m09s	134	1723	35.51°.		Flaps commanded up to 20°. Landing gear raised.
20h05m11s	123	1874	40.5°.		
20h05m12s					CAL676: (Two loud rings are audible but no communication from crew)
20h05m13s					CAL676: "*Tower CAL?*".

20h05m14s	104	2151		40 ° left	
20h05m16s		2327	42.72°.	9° right.	Flaps 20°. 1nm down runway.
20h05m21s					TWR: "*CAL676 confirm go-around*" (No response from CAL676).
20h05m25s	43	2751	0°.	38° left.	
20h05m29s	103	2527	-22°.	79° left.	
		(2627)			
20h05m34s	173	1779	-44.65°.	20° right	1.5nm down runway.
		(1799)			
20h05m36s	203	1319	-36.56°.		
No further data					

The normal procedure is that at or before decision height, some part of the runway, its boundary, or its lighting, must be clearly visible to the pilots for the landing to be continued. If there is no such visual contact, a `*go-around*' is required, whereby the aircraft flies up and away under take-off performance, and either returns for another try or proceeds to the alternate airport. The aircraft is required to have on board enough fuel for a flight to the alternate airport plus reserves of 45 minutes or 30 minutes.

According to Aviation Week and Space Technology, the aircraft veered to the left on the ILS, "*impacting on a road and striking buildings that run parallel to Runway 05/23L, approximately a mile past the threshold. Chinese Aviation Authority officials said the [aircraft] possibly suffered a tail strike to the left of the runway while a go-around was attempted.*" Flight International said "*The impact point was 2,400-2,700m (8-9,000ft) from the threshold of the adjacent 3,660m-long runway. A V-shaped gouge at the start of the debris trail was found and is believed to have been made by the A300's tailplane and indicating that the aircraft had a nose-up pitch attitude, thought possibly to be consistent with a stall during a go-around attempt.*

Both Flight International and Aviation Week reported that the gear appeared to be up, and Flight reported that "*the slats and flaps were not set fully down*", although the crew had acknowledged clearance to land. If the gear was up, and the pilot had noticed that he had not put the gear down, that would explain a go-around attempt. The engines "*were reported to have disintegrated, indicating they were at high thrust*", which is consistent with a go-around attempt but not with a landing. Apparently, the pilot had not declared an emergency. Since he had declared a go-around, the radio transmissions appeared to be routine.

Modeling Considerations
Pilot loss of control over the aircraft appears to have been the cause of this accident. Flight data recorder readings indicate that the approach to the runway was far too high for a safe landing, and that the crew lost control during a manually flown go-around in which extreme pitch attitudes and speeds were allowed to develop.

It may be important to observe that all of the altitudes at which control problems occurred up to and including the stall were altitudes at which sufficient pilot control-column pressure takes precedence over autopilot control, according to SB A300-22-6021, whose basic requirements have been a Taiwanese AD for some time. Thus the Nagoya situation, in which the autopilot worked against the pilot flying, because go-around mode had inadvertently been commanded, should not have happened in this case. In fact, the incident started at well above the altitude at which the original design which SB A300-22-6021 modifies allows pilot take-over with control-column force (it is also the case that the pilot has two other means of disconnecting the autopilot - the `big red button' on the control column, and the ON/OFF switch on the Flight Control Unit (FCU), on the glare shield on the right-hand side).

1.2 Korean Air Lines B747 CFIT accident in Guam (1997)

Approaching Won Pat International Airport on a Localizer-only ILS approach to Runway 6 Left at night, Korean Air Lines Flight 801 impacted Nimitz Hill at 658ft just a few hundred yards from the VORTAC antenna. The DME KE801 should have been used, and the aircraft was nearly 800ft below the minimum altitude at that point on the approach. Flight KAL 801 terminated as a CFIT into a hillside on approach to Guam. It is interesting because of the great number of errors made by ATC, by the airline operator and by the flight crew. It is also one of the world's greatest aviation tragedies with 228 fatalities. The accident occurred in the early morning hours compounding the fatigue of the captain which NTSB said was a contributing cause.

Initial Conditions

On August 6, 1997, about 01:42:26 Guam local time, Korean Air flight 801, a Boeing 747-3B5B (747-300), Korean registration HL7468, operated by Korean Air Company, Ltd., crashed at Nimitz Hill, Guam. Flight 801 departed from Kimpo International Airport, Seoul, Korea, with 2 pilots, 1 flight engineer, 14 flight attendants, and 237 passengers on board. The airplane had been cleared to land on runway 6 Left at A.B. Won Guam International Airport, Agana. After the flight crew made an initial sighting of Guam, Korean Air flight 801 encountered instrument meteorological conditions as the flight continued on its approach to Guam International Airport.

Sequence of Events

About 4 minutes before the flight, the crew was advised by ground control that the glide slope landing system was inoperative, according to the flight data recorder. Poor visibility in the dark was compounded by the onset of heavy rains near the airport. One of the crew was heard to ask if the glide slope was working and the co-pilot replied that it was not. Soon thereafter the pilot was heard to ask if the glide slope indicator was working. The sound of the automated ground collision system was then heard indicating 1000 feet altitude. After cockpit alarms sounded, the captain cut off the autopilot and prepared to pull up. Seconds before the crash at 01:42, the automated voice calling to "go around" was heard just before impact. There were no lights on Nimitz Hill where the flight burst into flames. The crew apparently was relying on the localizer beacon to determine their distance from the runway. A survivor said there was no indication from the cockpit that anything was wrong. They crashed into the hillside with their landing gear extended. The tower allowed time for a go around to be executed, about 25 minutes, before calling crash equipment.

Modeling Considerations
The National Transportation Safety Board determined that the probable cause of the Korean Air flight 801 accident was the captain's failure to adequately brief and execute the non precision approach and the first officer's and flight engineer's failure to effectively monitor and cross-check the captain's execution of the approach. Contributing to these failures were the captain's fatigue and Korean Air's inadequate flight crew training. Contributing to the accident was the Federal Aviation Administration's (FAA) intentional inhibition of the minimum safe altitude warning system (MSAW) at Guam and the agency's failure to adequately manage the system.

The safety issues in this report focus on flight crew performance, approach procedures, and pilot training; air traffic control, including controller performance and the intentional inhibition of the MSAW system at Guam; emergency response; the adequacy of Korean Civil Aviation Bureau (KCAB) and FAA oversight; and flight data recorder documentation. Safety recommendations concerning these issues are addressed to the FAA, the Governor of the Territory of Guam, and the KCAB.

The captain ignored the ground proximity alert. This may have been related to his fatigue from a series of long flights.

1.3 American Airlines B757 crash in Cali (1995)

An American Airlines Boeing 757, Flight 965, crashed near Buga, Columbia on December 20, 1995, at about 2138 EST. Flight 965 was a regularly scheduled passenger flight from Miami, FL to Cali, Colombia when it crashed 38 miles north of Cali into mountainous terrain during a descent under instrument flight rules. There were 156 passengers and 8 crewmembers aboard. Four passengers survived the accident.

The crash site was located in a rugged section of the San Jose mountains.. Darkness, the remote location, and fear of leftist guerrillas that frequent that area, reportedly delayed rescue efforts.

Initial Conditions
The approach ("MARTHA"/A320 checklist) was towards the Cali (CLO) 21 DME. The weather was overcast clouds 3700 up to 4800 MSL, scattered at 5200-8000, visibility 10 miles, moderate rain, winds 140@10 (surface), temp 85 degrees F. Nav 1 was set to the Cali/CLO VOR with a 193 course inserted. Nav 2 was set to the Tulua VOR to track the 202 radial. The ADF was tuned to PALMA NDB (274 khz).

Sequence of Events

At about 18.34 EST, American Airlines Flight 965 took off from Miami for a flight to Cali. At 21.34h, while descending to FL200, the crew contacted Cali Approach. The aircraft was 63nm out of Cali VOR (which is 8nm South of the airport)) at the time. Cali cleared the flight for a direct Cali VOR approach and report at Tulua VOR. Followed one minute later by a clearance for a straight in VOR DME approach to runway 19 (the Rozo 1 arrival). The crew then tried to select the Rozo NDB (Non Directional Beacon) on the Flight Management Computer (FMC). Because their Jeppesen approach plates showed 'R' as the code for Rozo, the crew selected this option. But 'R' in the FMC database meant Romeo. Romeo is a navaid 150nm from Rozo, but has the same frequency. The aircraft had just passed Tulua VOR when it started a turn to the left (towards Romeo). This turn caused some confusion in the cockpit since Rozo 1 was to be a straight in approach. Some 87 seconds after commencing the turn, the crew activated Heading Select (HDG SEL), which disengaged LNAV and started a right turn. The left turn brought the B757 over mountainous terrain, so a Ground Proximity (GPWS) warning sounded. With increased engine power and nose-up the crew tried to climb. The spoilers were still activated however. The stickshaker then activated and the aircraft crashed into a mountain at about 8900ft (Cali field elevation being 3153ft).

Modeling Considerations
Aeronautical Civil determines that the probable causes of this accident were:

1. The flight crew's failure to adequately plan and execute the approach to runway 19 at SKCL and their inadequate use of automation;
2. Failure of the flight crew to discontinue the approach into Cali, despite numerous cues alerting them of the inadvisability of continuing the approach;
3. The lack of situational awareness of the flight crew regarding vertical navigation, proximity to terrain, and the relative location of critical radio aids;
4. Failure of the flight crew to revert to basic radio navigation at the time when the FMS-assisted navigation became confusing and demanded an excessive workload in a critical phase of the flight.

Contributing to the cause of the accident were:

1. The flight crew's ongoing efforts to expedite their approach and landing in order to avoid potential delays;
2. The flight crew's execution of the GPWS escape maneuver while the speed brakes remained deployed;
3. FMS logic that dropped all intermediate fixes from the display(s) in the event of execution of a direct routing;
4. FMS-generated navigational information that used a different naming convention from that published in navigational charts." (Aarons 1996)

1.4 A300 crash in Nagoya (1994)

China Airlines Airbus Industrie A300B4-622R B 1816 took off from Taipei International Airport at 0853 UTC on April 26, 1994 and continued flying according to its flight plan.

About 1116 UTC, while approaching Nagoya Airport for landing, the aircraft crashed into the landing zone close to E1 taxiway of the airport. The aircraft ignited, and was destroyed killing 264 persons (249 passengers including 2 infants and 15 crew members) and seriously injuring 7 passengers. The Nagoya scenario is well known because the autopilot apparently worked against the pilot flying, because go-around mode had inadvertently been activated when it should not have been.

Initial Conditions
Aeronautical meteorological observations at Nagoya Airport reported light rain and light winds. There was light clouds the winds were out of 280 at 10kts visibility was 15 km and the temperature was 20 C.

Sequence of Events
China Airlines' Flight 140 (from Taipei International Airport to Nagoya Airport), B1816, took off from Taipei International Airport at 0853 UTC on April 26, 1994. The flight was heading to Nagoya Japan at a cruising speed of 465 knots, FL 330. The total estimated enroute time was 2 hours and 18 minutes. The digital flight data recorder (DFDR) shows that the aircraft reached FL 330 about 0914 and continued its course toward Nagoya Airport in accordance with its flight plan.

The aircraft, which was controlled by the F/O, while cruising at FL 330 was cleared at 10:47:35 to descend to FL 210 by the Tokyo Area Control Center and commenced descent. The CAP briefed the F/0 on approach and landing for about 25 minutes prior to beginning the descent.

At 10:58:18, communication was established with Nagoya Approach Control. The aircraft began to descend and decreased its speed gradually, in accordance with the clearances given by Approach Control.

At 11:04:03, the aircraft was instructed by Nagoya Approach control to make a left turn to a heading of 0100. Later, at 11:07:14, the aircraft was cleared for ILS approach to Runway 34 and was instructed to contact Nagoya Tower.

The aircraft passed the outer marker at 11:12:19, and at 11:13:39, received landing clearance from Nagoya Tower. At this time, the aircraft was reporting winds 290 degrees at 6 knots. Under manual control, the aircraft continued normal ILS approach.

At 11:14:05, however, while crossing approximately 1,070 ft pressure altitude, the F/0 inadvertently triggered the GO lever. As a result the aircraft shifted into GO AROUND mode leading to an increase in thrust. The Captain (CAP) cautioned the F/0 that he had triggered the GO lever and instructed him, saying, "disengage it". The aircraft leveled off for about 15 seconds at approximately 1,040 ft pressure altitude (at a point some 5.5 km from the Runway). The CAP instructed the F/O to correct the descent path that had become too high. The F/0 acknowledged this. Following the instruction, the F/O applied nose down elevator input to adjust its descent path, and consequently the aircraft gradually regained its normal glide path. During this period, the CAP cautioned to the F/0 twice that the aircraft was in GO AROUND Mode. At 11:14:18, both autopilots No.2 and No.1 were engaged almost simultaneously when the aircraft was flying at approximately 1,040 ft pressure altitude, a point 1.2 dots above the glide slope.

Both autopilots (APs) were used for the next 30 seconds. There is no definite record in the cockpit voice recorder (CVR) of either the crew expressing their intention or calling out to use the AP. For approximately 18 seconds after the AP was engaged, the THS gradually moved from 5~30 to 12.30, which is close to the maximum nose-up limit. The THS remained at 12.30 until 11:15:11. During this period, the elevator was continually moved in the nose-down direction. In this condition, the aircraft continued its approach, and at 11:15:02, when it was passing about 510 ft pressure altitude (at a point approximately 1.8 km from the runway), the CAP, who had been informed by the F/O that the THR had been latched, told the F/0 that he would take over the controls. Around this time, the THR levers had moved forward greatly, increasing EPR from about 1.0 to more than 1.5. Immediately afterwards, however, the THR levers were retarded, decreasing EPR to 1.3. In addition, the elevator was moved close to its nose-down limit when the CAP took the controls.

At 11:15:11, immediately after the CAP called out "Go lever", the THR levers were moved forward greatly once again, increasing EPR to more than 1.6. The aircraft therefore began to climb steeply. The F/0 reported to Nagoya Tower that the aircraft would go around, and Nagoya Tower acknowledged this. The aircraft started climbing steeply, AOA increased sharply and CAS decreased rapidly. During this period, the THS decreased from 12.30 to 7~40, and SLATS/FLAPS were retracted from 30/40 to 15/15 after the F/0 reported "Go Around" to Nagoya Tower.

At 11:15:17, the GPWS activated Mode S warning "Glide Slope" once, and at 11:15:25, the stall warning sounded for approximately 2 seconds. At 11:15:31, after reaching about 1,730 ft pressure altitude (about 1,790 ft radio altitude), the aircraft lowered its nose and began to dive. At 11:15:37, the GPWS activated Mode 2 warning "Terrain, Terrain" once, and the stall warning sounded from 11:15:40 to the time of crash.

At about 11:15:45, the aircraft crashed into the landing zone close to the E1 taxiway. With the APs engaged and with GO AROUND mode still engaged, the F/O continued pushing the control wheel in accordance with the Captain's instructions. As a result of this, the THS (Horizontal Stabilizer) moved to its full nose-up position and caused an abnormal out-of-trim situation. The crew continued the approach, unaware of the abnormal situation. The Angle of Attack (AOA) increased, the Alpha Floor function [a particular automatic control function intended for situations in which a high AOA, the incidence of the wings to the air, was too high which led to a stall when the pitch angle increased excessively. It is considered that, at this time, the Captain (who had now taken the controls), judged that landing would be difficult and opted for go-around. The aircraft began to climb steeply with a high pitch angle attitude. The Captain and the F/O did not carry out an effective recovery operation, and the aircraft crashed.

Modeling Considerations

The co-pilot, who was flying, had inadvertently triggered the *Take-off/Go-around* (TOGA) switch on the engine power levers. This caused the Flight Director (an advisory device on the Attitude Indicator) to switch to GO-AROUND mode, and increased thrust on the engines. The autopilots were subsequently engaged, with GO-AROUND mode still engaged. The co-pilot applied heavy nose-down forces to the control column under the Captain's instructions, and continued to do so. The autopilot on this A300 did not disengage under these forces, specifically because of its design. Thus it attempted to counteract the nose-down attitude of the aircraft by putting in nose-up trim on the Horizontal Stabilizer, causing an abnormal out-of-trim situation. The copilot and the autopilot were thus fighting each other. The abnormal nose-up trim caused the aircraft to pitch up drastically, losing airspeed very quickly, stall, and impact the ground tail-first.

The pilot flying did not disconnect the autopilot, despite repeated instructions from the captain to do so (the A300 Operations Manual explicitly requires the pilot to disconnect the autopilot in such circumstances) until 40 seconds after it was noticed. The pilot flying tried to force the nose of the airplane down, and the autopilot, in go-around mode, reacted to the lack of climb by trimming pitch even further up. When the pilot eventually stopped pushing and the AP was disconnected, the captain took over. However, without the forward pressure on the yoke, the nose rose sharply, due to the extreme nose-up trim, and the plane stalled in an extreme nose-high configuration, and hit the ground tail-first.

The AAIC [Japanese Air Accident Investigation Commission PBL] determined that the following factors, as a chain or a combination thereof, caused the accident:

1. The F/O inadvertently triggered the Go lever. It is considered that the design of the GO lever contributed to it: normal operation of the thrust lever allows the possibility of an inadvertent triggering of the GO lever.

2. The crew engaged the APs while GO AROUND mode was still engaged, and continued approach.

3. The F/O continued pushing the control wheel in accordance with the CAP's instructions, despite its strong resistive force, in order to continue the approach.

4. The movement of the THS conflicted with that of the elevators, causing an abnormal out-of-trim situation.

5. There was no warning and recognition function to alert the crew directly and actively to the onset of the abnormal out-of-trim condition.

6. The CAP and F/O did not sufficiently understand the FD mode change and the AP override function. It is considered that unclear descriptions of the AFS (Automatic Flight System) in the FCOM (Flight Crew Operating Manual) prepared by the aircraft manufacturer contributed to this.

7. The CAP's judgment of the flight situation while continuing approach was inadequate, control take-over was delayed, and appropriate actions were not taken.

8. The Alpha-Floor function was activated; this was incompatible with the abnormal out-of-trim situation, and generated a large pitch-up moment. This narrowed the range of selection for recovery operations and reduced the time allowance for such operations.

9. The CAP's and F/O's awareness of the flight conditions, after the PlC took over the controls and during their recovery operation, was inadequate respectively.

10. Crew coordination between the CAP and the F/O was inadequate.

11. The modification prescribed in Service Bulletin SB A300-22-6021 had not been incorporated into the aircraft. The modification has to do with pilot inputs to the control column overriding the autopilot. The A300 was originally designed so that this could not happen below 1,500 feet. The intent was to prevent inadvertent control column input from disturbing an autopilot-controlled landing. The Airbus A300 is delivered with Category III capable auto land already installed. Category III auto lands require the autopilot and may be performed in circumstances in which a manual landing by the pilots is disallowed. The control is very sensitive, and Airbus wished to eliminate the possibility that inadvertent inputs from the pilot could disturb an auto land.

12. The aircraft manufacturer did not categorize the SB A300-22-6021 as "Mandatory", which would have given it the highest priority. The airworthiness authority of the nation of design and manufacture did not issue promptly an airworthiness directive pertaining to implementation of the above SB.

1.5 REFERENCES

Aarons, R.N. Improvements needed in FMS Human Factors . Business & Commercial Aviation Nov. 1996 (144, 146, 160);

Hohl, M., Ladkin, P.B., Loer K. WB-Graph of the A300 accident at Nagoya. University of Bielefeld Article RVS-OCC-98-02. 19 August 1998 http://www.rvs.unibielefeld.de/publications/Incidents/DOCS/ComAndRep/Nagoya/NagoyaWB.html

Ladkin, P.B. The crash of Flight CI676, a China Airlines airbus A300, Taipei, Taiwan. February 1998. What we know so far. University of Bielefeld Article RVS-J-98-01. 18 March, 1998 http://www.rvs.unibielefeld.de/publications/Incidents/DOCS/Research/Rvs/Misc/Additional/Reports/taipei/AERAD-Taipei#AERAD-Taipei

Sogame, H. and Ladkin, PB. Aircraft Accident Investigation report 96-5: China Airlines, A300B4-622R, B1816 Nagoya Airport, University of Bielefeld Report 96-5. July, 1996 http://www.rvs.unibielefeld.de/publications/Incidents/DOCS/ComAndRep/Nagoya/nagoyarep/nag-contents.html